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An Integrated Stream Classification System for Texas

by

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Abstract

The recently-passed Senate Bill 3 tasks stakeholders and regulators with determining and reviewing environmental flow needs. A stream classification system was developed and tested for Texas to support analyses of environmental flows based on quantitative data for 18 distinguishing parameters encompassing watershed and stream channel processes from four disciplines: (1) Hydrology & Hydraulics, (2) Water Quality, (3) Geomorphology & Physical Processes, and (4) Climatology. The State of Texas was partitioned into five regions: East Texas, South-Central Texas, Lower Rio Grande Basin, West Texas, and North-Central Texas by 8-digit Hydrologic Unit Code (HUC) basins.

This stream classification system might be used to: (1) discern likely similarities and differences between rivers and streams of the State, (2) remotely characterize stream segments for which resources are insufficient for detailed field studies, (3) recognize streams and watersheds of the State as having common identities, (4) allow conclusions drawn from an instream flow study from a particular river reach to have a wider applicability than the particular study site, and (5) assist in prioritization of rivers and reaches for future instream flow studies.

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List of Acronyms

BAIT	Bio-aquatic Informatics for Texas
BEG	Bureau of Economic Geology
BFI	Base flow Index
CFS	Cubic feet per second
CONUS	Conterminous United States
CRWR	Center for Research in Water Resources
DO	Dissolved Oxygen
EDU	Ecological Drainage Unit
ESRI	Environmental Systems Research Institute
GAT	Geologic Atlas of Texas
HAT	Hydrologic Assessment Tool
HCDN	Hydro-Climatic Data Network
HUC	Hydrologic Unit Code
IBWC	International Boundary and Water Commission
IQR	Interquartile Range
ITC	Irrigation Technology Center
MAF	Mean annual flow
MAV	Mean annual velocity
NAWQA	National Water Quality Assessment
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NHDPlus	National Hydrography Dataset Plus
NLCD	National Land Cover Dataset
NRC	National Research Council
NRCS	National Resource Conservation Service
PET	Potential Evapotranspiration
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RSF	River Styles Framework
SB2	Senate Bill 2
SB3	Senate Bill 3
SQL	Structured Query Language

STATSGO	State Soil Geographic
STORET	Storage and Retrieval
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TIFP	Texas Instream Flow Program
TNC	The Nature Conservancy
TNRIS	Texas Natural Resources Information System
TPWD	Texas Parks and Wildlife Department
TRACS	TCEQ Regulatory Activities Compliance Systems
TSS	Total Suspended Solids
TWDB	Texas Water Development Board
UROM	Unit Runoff Method
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VBA	Visual Basic for Applications
WBD	Watershed Boundary Dataset
WWF	World Wildlife Fund

1. STREAM CLASSIFICATION SYSTEM INTRODUCTION

1.1 Background

1.1.1 PROJECT PURPOSE

The Texas Commission on Environmental Quality (TCEQ) has the statutory obligation to review water rights applications for their potential impacts on aquatic resources and set environmental flow requirements. The agency carries out this charge by relying on a hydrologic desktop method, publicly-available data, and site-specific information collected in the field to make environmental flow determinations. The TCEQ-designated water quality management segments with studies currently underway represent a small fraction of the total number of free-flowing rivers (i.e., not inland water bodies, tidal reaches or coastal segments) in Texas. Studies on the remaining segments will take more time and resources than are available, yet it is important to characterize the other segments to determine appropriate instream flow requirements.

Thus, the purpose of this project was to use Geographic Information System (GIS) technology to organize existing information relevant to the understanding of Texas streams and rivers (i.e., water quality, geologic and geomorphic, hydrologic and hydraulic, and biologic data) and to develop a classification scheme such that particular classes or regions of streams and rivers could be recognized as having a common identity.

1.1.2 PROJECT MOTIVATION

The value and need for stream classification was recognized in the May 2006 Texas Instream Flow Program (TIFP) *Draft Texas Instream Flow Studies: Technical Overview*:

> The TIFP has identified six priority river basins in which to initiate studies and implement recommendations. These priority basins represent a small subset of the total number of rivers and streams in the state. Ultimately, the program will need to be expanded to encompass these other rivers and streams. Expansion should be based on a priority-setting system and may involve additional studies. In addition,

> it is anticipated that classification tools will be developed to aid in the application of instream flow standards to the state's myriad rivers and streams. It would be a near-impossible task to individually study all the state's 191,000 river miles. Derivation of hydrologically, ecologically, and geomorphologically similar aquatic ecosystem units would enable the establishment and application of streamlined methods for developing instream flow recommendations.

Additionally, a recent paper by Arthington, Bunn, Poff, and Naiman (2006) put forth the concept of stream classification as a means to "bridge the gap between simple hydrological 'rules of thumb' and more comprehensive environmental flow assessments and experimental flow restoration projects":

> Rather than attempting to manage for the 'uniqueness' of every individual river's natural flow regime, we identify 'classes' of streams based on key attributes of flow variability, and then calibrate relationships between alterations in each flow attribute and measures of ecological condition for each stream class.

The goal of this project was to develop a classification scheme such that particular classes or regions of streams and rivers could be recognized as having a common identity or sharing common attributes. Accordingly, conclusions drawn from instream flow studies in particular river reaches might be generalizable.

1.2 Legislative Framework

1.2.1 SENATE BILL 2 - SCIENCE

The 77th session of the Texas Legislature passed Senate Bill 2 (SB2) in 2001, directing the Texas Commission on Environmental Quality (TCEQ), Texas Parks and Wildlife Department (TPWD), and Texas Water Development Board (TWDB) (hereinafter referred to as "the agencies") to "…jointly establish and continuously maintain an instream flow data collection and evaluation program…" and to "…conduct studies and analyses to determine appropriate methodologies for determining flow conditions in the state rivers and streams necessary to support a sound ecological environment," which was further defined by the agencies as " a functioning ecosystem characterized by intact, natural processes, resilience, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region." The agencies' vehicle for implementing SB2 is the Texas Instream Flow Program (TIFP) (Senate Bill 2, TIFP 2006).

Six subbasins were identified by the agencies for TIFP priority study based on potential water development projects, water rights permitting issues, and other factors. They are: the Lower Sabine, Middle Trinity, Middle and Lower Brazos, Lower Guadalupe, and Lower San Antonio River Basins. Specific instream flow studies were scheduled to be completed for each priority basin by December 31, 2010, but Senate Bill 3 (SB3), passed in 2007 by the 80th Legislature, extended this deadline to December 31, 2016 (Texas Legislature 2001, TIFP 2002, Texas Legislature 2007).

1.2.2 SENATE BILL 3 - IMPLEMENTATION

Passed in 2001, Senate Bill 2 established the TIFP to collect data and determine the flow regime protective of the ecological environment. Often referred to colloquially as "the science bill," it did not address implementation nor did it include consideration of water users and uses external to the riverine ecosystem (Texas Legislature 2001, TIFP 2002). Senate Bill 3 (SB3), the implementation bill, was proposed in the 79th Legislative Session (2005) but was not passed until 2007 by the 80th Legislature.

SB3 establishes the who, when, and how of environmental flow implementation in the State of Texas by creating:

- an environmental flows advisory group,
- an environmental flows advisory committee,
- bay and basin stakeholder committees, and
- bay and basin expert science teams.

This hierarchy of rule makers, scientists and stakeholders is variously tasked with:

- identifying environment flow needs for the bays and basins of the State,
- reviewing the determinations,
- building consensus through balanced representation by region,
- considering the environmental flow needs in light of present and future water needs and other uses,

- establishing public and private market approaches for satisfying flow needs, and
- developing a formal process of review and adaptive management (Texas Legislature 2007).

SB3 mandate that the TCEQ shall adopt the environmental flow standards recommended by the basin and bay area stakeholders committee by September 1, 2010. SB3 does not explicitly address how the results of the SB2 priority studies to be completed by December 31, 2016 will be incorporated into the environmental flow standards to be promulgated by TCEQ. However, SB3 includes provisions for an adaptive management-based program of periodic reevaluation, validation, and refinement based on the best available science; this likely includes the SB2 study findings.

Furthermore, SB3 alters the conditions under which water rights permits are issued by TCEQ such that "in its consideration of an application for a permit to store, take, or divert water…" the TCEQ must consider the environmental flow requirements of the bays and basins, and any new permits or new permit modifications must include provisions for adjustment to allow for adaptive management. With regards to the variability of hydrologic systems, SB3 mandates that "Environmental flow standards…must consist of a schedule of flow quantities, reflecting seasonal and yearly fluctuations that may vary geographically by specific location in a river basin and bay system" (Texas Legislature 2007).

2. EXISTING STREAM CLASSIFICATION SCHEMES

2.1 Freshwater Ecosystem Classification

Numerous classification schemes have been developed for various regions of the world based on variables from a single discipline. By considering a limited subset of conditions representing the riverine environment, these classification schemes are inherently limited in application and value for holistic considerations such as the development of instream flow prescriptions. The preponderance of classifications have been based on hydrology and geomorphology.

The World Wildlife Fund (WWF) developed freshwater ecoregions “which are derived by aggregating and subdividing watersheds based on the distribution patterns of aquatic species. With watersheds as their foundation, the freshwater ecoregions can be effective units for conservation planning” (Abell et al. 2000). The Nature Conservancy (TNC) subsequently developed a freshwater classification scheme for nationwide application and applied the scheme to much of Texas in support of the Conservancy’s internal ecoregional planning process (Fitzhugh 2005, Higgins et al. 2005) (Figure 1). The system is a four-tiered, hierarchical approach based on predominantly abiotic parameters, with the first tier being the WWF freshwater ecoregions. The original TNC scheme was crafted prior to the availability of multiple valuable electronic datasets (notably NHDPlus) and was managed as shapefiles in ESRI ArcView 3.2 software. TNC is currently in the process of ‘maturing’ the classification scheme in Texas and reclassifying certain regions of the State (Smith 2006).

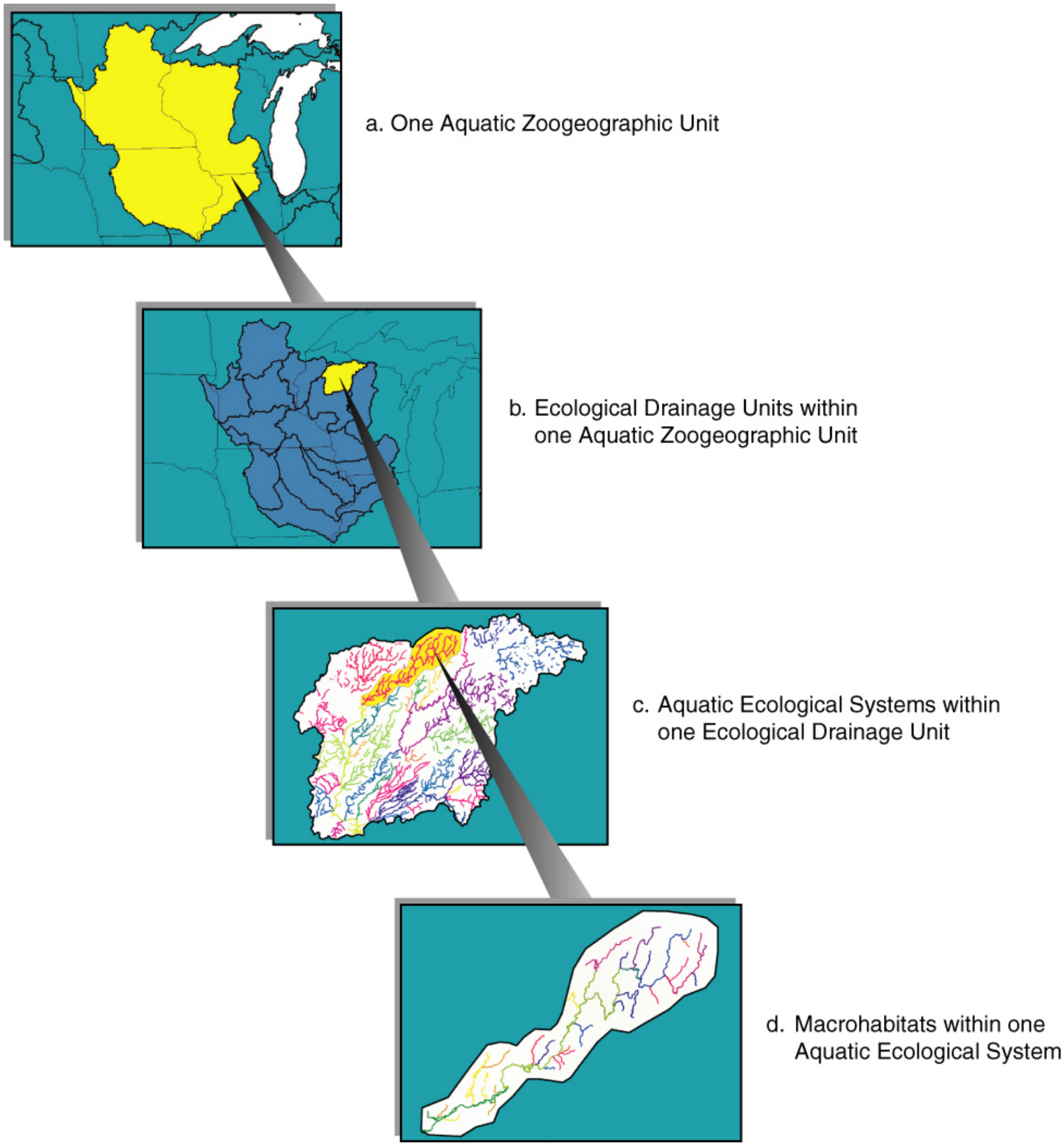

Figure 1. The Nature Conservancy's freshwater ecosystem classification hierarchy (from Higgins et al. 2005).

Table 1. TNC's freshwater ecosystem classification levels and separation factors (Smith 2006).

Level	**Examples**	**Description**	**Separation Factors**
Ecoregion	1) Edwards Plateau 2) Pineywoods	Similar climate and physiography that corresponds to broad vegetation regions	Forest type, shrubland vs. grassland
Ecological Drainage Unit (EDU)	1) Guadalupe/San Antonio 2) Nueces 3) Lower Rio Grande/Devils	Aggregates of watersheds that share ecological, biological, and aquatic zoogeographical characteristics, by 8-digit HUC. Within each EDU there is a regional subset of aquatic ecosystem types	Physiography, zoogeography, watershed
Aquatic Ecological System	1) Medium sized perennial prairie streams 2) Small Edwards Plateau rivers 3) Piney Woods bayous	Hydrological subunits of EDU's. Defined by landscape position of a stream size-class within 1 or 2 stream orders that represent a dynamic assemblage of aquatic communities	Size, drainage network position, connectivity, hydrologic regime, geology
Macrohabitat	1) Meandering, low gradient, riffle/pool plains stream 2) Medium gradient, foothills beaver-pond influenced stream	Different valley segment types of stream reaches (think stream reach of 30km), within segments, relatively homogeneous. Finest scale classification unit on the maps.	Surficial geology, drainage network position, connectivity, hydrologic regime, geology

2.2 River Environment Classification

The New Zealand River Environment Classification (REC) is a classification scheme that has been considered and/or applied in other countries since its inception in 2002, including: Australia, Belgium, Chile, France, and the United States (Snelder and Biggs 2002, Snelder et al. 2004, Biggs 2007, Kilroy et al. 2007, Norris et al. 2007). REC is a physically-based system of nested hierarchical variables that each operate on different spatial scales. REC incorporates climate, topography, geology, and land cover, as defined by:

- Climate: temperature, precipitation, potential evapotranspiration (PET)
- Flow source: mountain, hill, low elevation, or lake
- Geology: dominant rock type
- Land cover: vegetation types at a 1-10 sq. km scale
- Network position: Strahler stream order (or distance from river mouth, or average section elevation)
- Valley landform: primarily slope, but also lateral (floodplain) and vertical (hyporheic) connectivity, hydraulic geometry, bankfull discharge, local stream power, sediment size range, and riparian conditions.

In the order presented above, the variables are taken into consideration at diminishing spatial scales ranging from the order of 10^5 sq. km for climate down to 10^1 to 10^0 sq. km for land cover, network position, and valley landform. The REC was tested in 2005 via analyses of 13 streamflow variables from 335 gages across New Zealand to prove that inter-class differences were greater than intra-class differences and to quantify the “strength” of the classification compared to previously-developed geographic and ecoregion systems (Snelder and Biggs 2002, Snelder et al. 2004, Snelder and Hughey 2005, Snelder et al. 2004, Snelder et al. 2005).

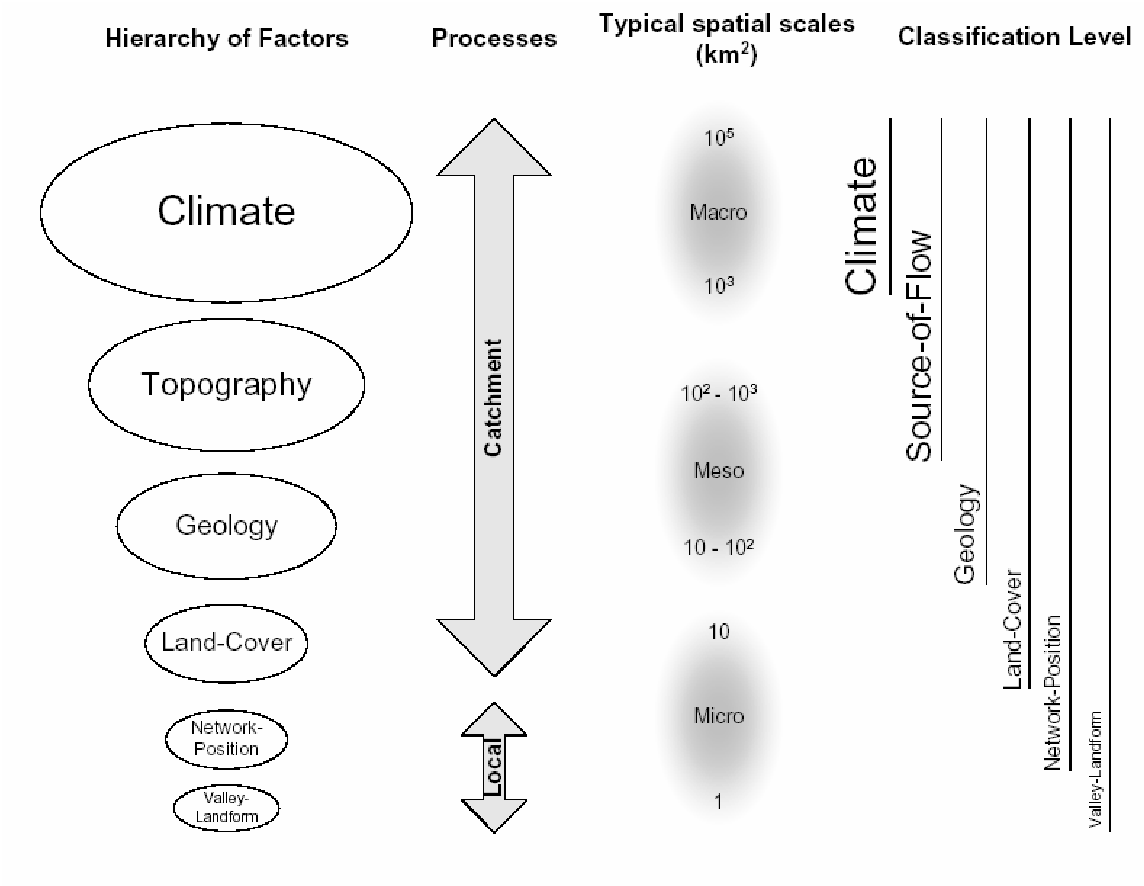

Figure 2. River Environment Classification hierarchy (from Snelder and Biggs 2002).

2.3 River Styles Framework

There are a host of geomorphic classifications, each with a differing approach and differing purpose, including those proposed by Rosgen (1994) and Kondolf et al. (2003). One such scheme generating much recent interest in the river science community is the River Styles Framework from the New South Wales Department of Land and Water Conservation in Australia (Brierley and Fryirs 2000, Thomson et al. 2001, Brierley et al. 2002, Fryirs 2003, Thomson et al. 2004, Brierley and Fryirs 2005, Chessman et al. 2006). Based on work conducted in 2005 by Dr. Jonathan Phillips of Copperhead Road

Geoscience and of the University of Kentucky, the River Styles Framework has been selected as the geomorphic classification system of choice for the TIFP.

River Styles Framework "is not a classification system, per se, but a flexible, dynamic approach to river characterization" (Phillips 2006). River Styles Framework is designed to both assess current (static) and historical conditions and to forecast likely trajectories of change, thus moving beyond the traditional thinking on the subject of equilibrium and into an assessment of sensitivity and resiliency characterized by complex nonlinear dynamics. River Styles Framework differs from traditional categorical classification schemes such as the Rosgen Stream Classification System because it is "specifically intended to incorporate evolutionary pathways of the fluvial system, rather than static conditions that are presumed to be related to stable equilibrium states." (Phillips 2006) The NRC (2005) review recognizes the importance of geomorphic classification for the TIFP and also the merit of evaluating both the current equilibrium status of a river system and also indicators of recent and historic change. Such an approach would tend to favor the strengths of a dynamic characterization system like the River Styles Framework over traditional, static categorization systems.

Under the River Styles Framework, the geomorphology of a river system is examined first and a classification system is then developed based on the geomorphic findings. This a posteriori classification is set within a nested hierarchical framework where various physically-based components are used to distinguish between classes at each hierarchical level (Table 2).

Table 2. River Styles Framework hierarchy (Brierley and Fryirs 2005, Phillips 2006).

Hierarchical Level	**Determining Characteristics**
Watershed	Drainage divides, hydrologic units
Landscape unit	Geology, elevation, relief, slope, morphology
River style	Length of channel (and valley) with a characteristic assemblage of geomorphic units
Geomorphic unit	Instream and floodplain landforms reflecting distinct form-process associations
Hydraulic unit	Uniform patch of flow and substrate
Microhabitat	Individual elements, such as logs, boulders, and scour holes.

The recommended methodology to conduct a River Styles Framework assessment is organized into stages and steps (Figure 3), and an example of a completed assessment for the Bega Catchment in New South Wales, Australia is presented in Figure 4.

STAGE ONE: Catchment-wide baseline survey of river character and behaviour

Stage One, Step One: Assess regional and catchment setting controls
Stage One, Step Two: Define and map River Styles across the catchment
Stage One, Step Three: Interpret controls on the character, behaviour and downstream patterns of River Styles

STAGE TWO: Catchment-framed assessment of river evolution and geomorphic river condition

Stage Two, Step One: Determine the capacity for adjustment of the River Style
Stage Two, Step Two: Assess river evolution as a basis to identify irreversible geomorphic change and a reference condition
Stage Two, Step Three: Determine and explain the geomorphic condition of the reach

STAGE THREE: Assessment of the future trajectory of change and geomorphic river recovery potential

Stage Three, Step One: Determine the trajectory of river change
Stage Three, Step Two: Assess river recovery potential: Place reaches in their catchment context and assess limiting factors to recovery

STAGE FOUR: River management applications and implications: Catchment based vision building, identification of target conditions and prioritisation of management efforts

Stage Four, Step One: Develop a catchment-framed physical vision
Stage Four, Step Two: Identify target conditions for river rehabilitation and determine the level of intervention required
Stage Four, Step Three: Prioritise efforts based on geomorphic river condition and recovery potential
Stage Four, Step Four: Monitor and audit improvement in geomorphic river condition

Figure 3. Stages and steps in the River Styles Framework (Brierley and Fryirs 2005).

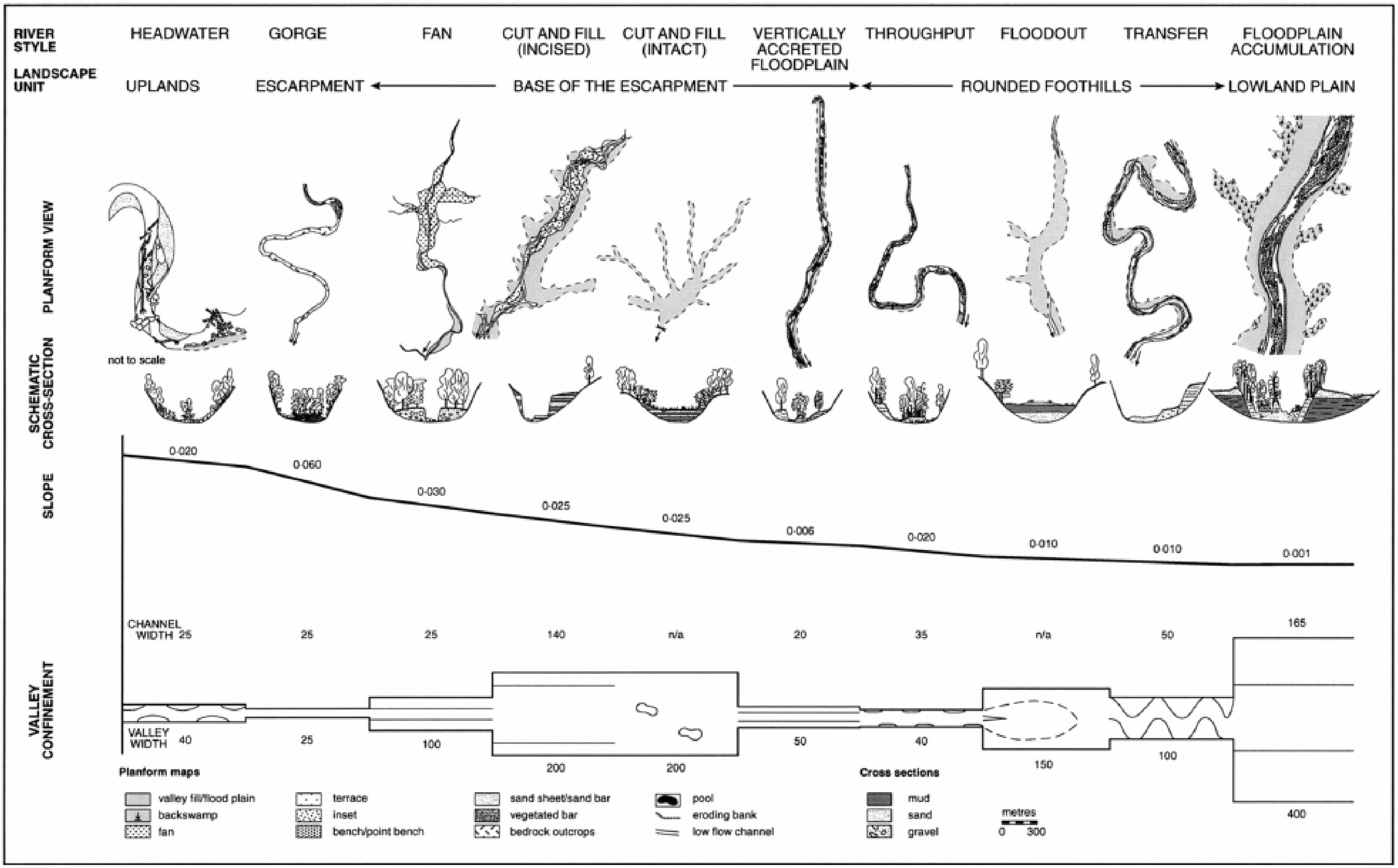

Figure 4. Summary controls on the character and behavior of River Styles in Bega Catchment, New South Wales, Australia (Brierley and Fryirs 2000)

The successful implementation of River Styles Framework requires extensive field work and a considerable understanding of geomorphic principles. River Styles Framework utilizes common descriptors but has no *a priori* styles, so the value of this system for understanding and classifying (grouping) the rivers of Texas for the TIFP or other purposes is unclear.

2.4 Additional Classification Systems

Poff (1996) put forth a hydrogeographic regionalization of unregulated streams in the contiguous United States based on a study of flow regime characteristics and flow sources at 420 gaged sites; the ten classes were pared down into six in Olden and Poff (2003). The results of the national study likely bear little fruit for application in Texas, however, due to the lack of study locations within the State or other hydrologically-similar regions (Figure 5).

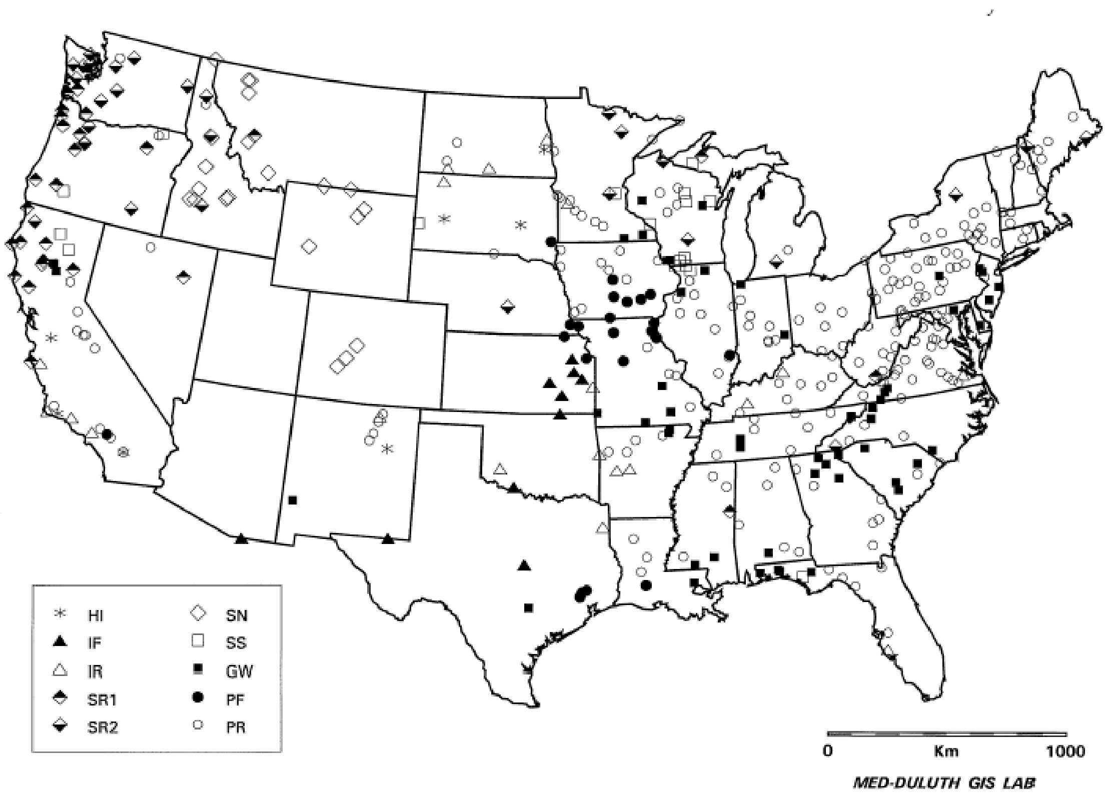

Figure 5. Location and stream classification of the 420 gages of Olden and Poff (2003).

Olden and Poff's (2003) regionalization forms the basis for the USGS Hydroecological Integrity Assessment Process. Under the process, the State of New Jersey has developed a state-specific classification tool to partition that state's gaged streams into four stream classes, termed A, B, C, and D, by their relative degree of skewness of daily flows (high versus low) and by the relative frequency of low flow events per year (high versus low) (Figure 6). Group B streams have stable, groundwater-supported streamflow with a high base flow index; Group D streams are small and flashy with little base flow; Groups A and C are intermediate streams. The two measures employed provide an indication of the relative degree of flashiness of gaged streams across the State as well as the relative degree of base flow influence, as indicated by the MA5 and FL3 statistics within the USGS's Hydrologic Assessment Tool (HAT):

- MA5 – The skewness of the entire flow record is computed as the mean for the entire flow record (MA1) divided by the median (MA2) for the entire flow record (dimensionless - spatial).
- FL3 – Frequency of low pulse spells. Compute the average number of flow events with flows below a threshold equal to 5 percent of the mean flow value for the entire flow record. FL3 is the average (or median - Use Preference option) number of events (number of events/year – temporal).

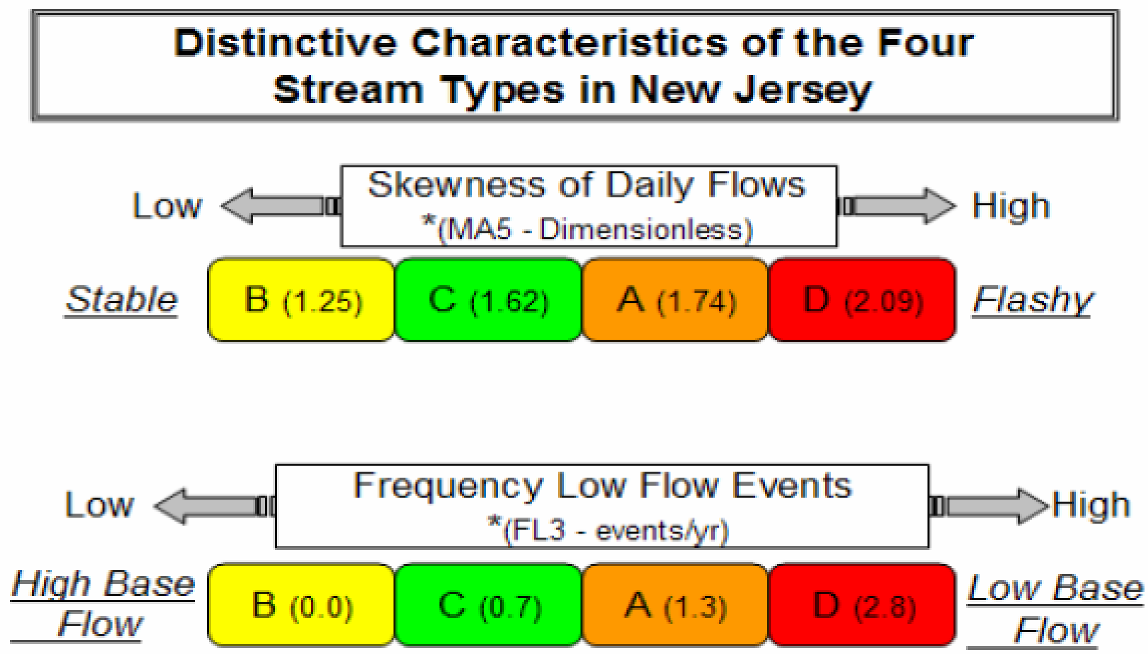

Figure 6. Classification rules employed by the USGS New Jersey Stream Classification Tool (Henriksen et al 2006).

Another hierarchical system, based on the spatial and temporal scale of various processes and forcings is the U.S. Forest Service Aquatic Ecological Units in North America (Nearctic Zone) Classification (Figure 7). This hierarchy was developed in recognition of the varying and overlapping scales of influence, both in time and in space, of various forcing functions present in a riverine ecosystem (Maxwell et al 1995).

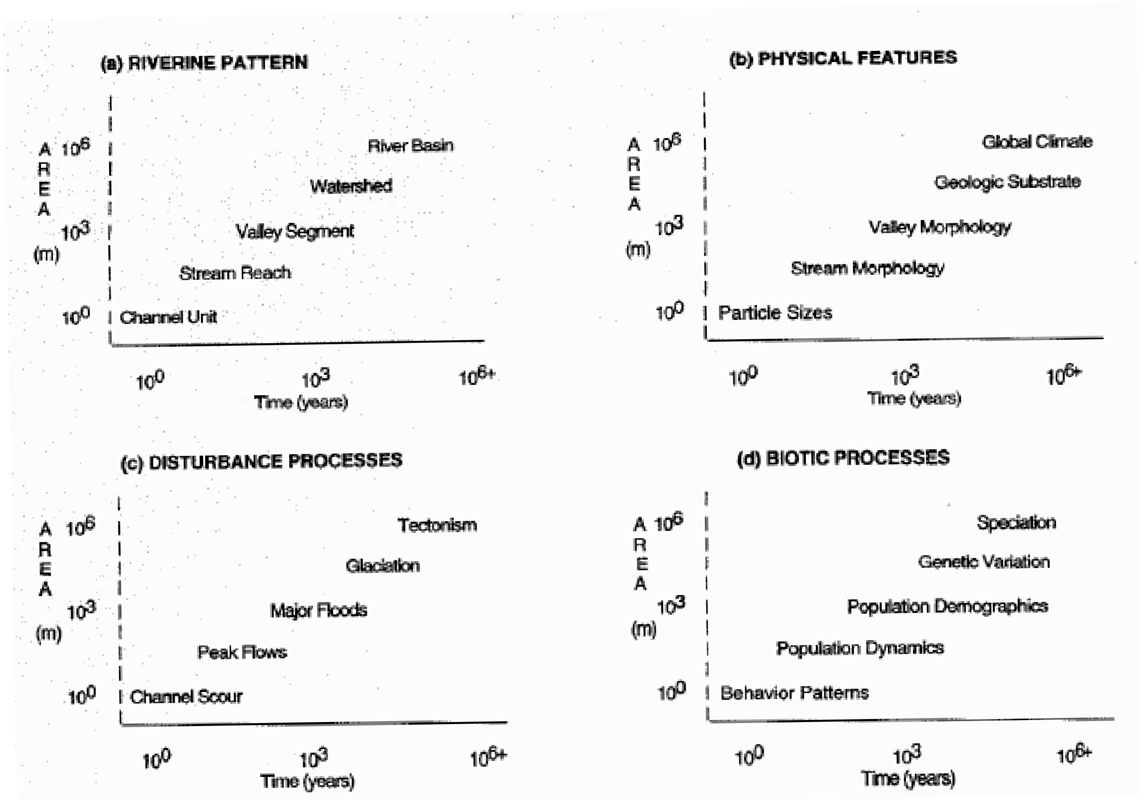

Figure 7. US Forest Service spatio-temporal scaled patterns of (a) riverine systems; (b) physical features; (c) disturbance processes; and (d) biotic processes (from Maxwell et al 1995).

3. STREAM CLASSIFICATION SYSTEM FRAMEWORK

3.1 Conceptual Framework

To develop and apply an integrated stream classification system, the appropriate data must first be obtained and then assembled in a logical, systematic framework, otherwise known as a data model. This data aggregation and mediation is essential and must be accomplished before any classification schemes are considered or applied. Conceptually, data integrated into the data model are organized into themes by discipline, much like in the ArcHydro I data model for surface water (Figure 8) (Zeiler 1999, Maidment 2002).

Figure 8. Data model thematic layers that organize the data by discipline.

3.2 Physical Settings for Instream Flows in Texas

3.2.1 Generalized Districts

A qualitative regionalization of Texas streams and rivers is presented in the National Research Council Committee (2005) review of the Texas Instream Flow Program that familiarizes readers with the "physical settings for instream flows in Texas." In the current project, this qualitative regionalization and its boundaries were examined using quantified criteria.

The State of Texas was partitioned into five regions: East Texas, South-Central Texas, Lower Rio Grande Basin, West Texas, and North-Central Texas via a series of qualitative parameters. Here, a mapping of the NRC (2005) text was interpreted by 8-digit Hydrologic Unit Code (HUC) basin (Figure 9).

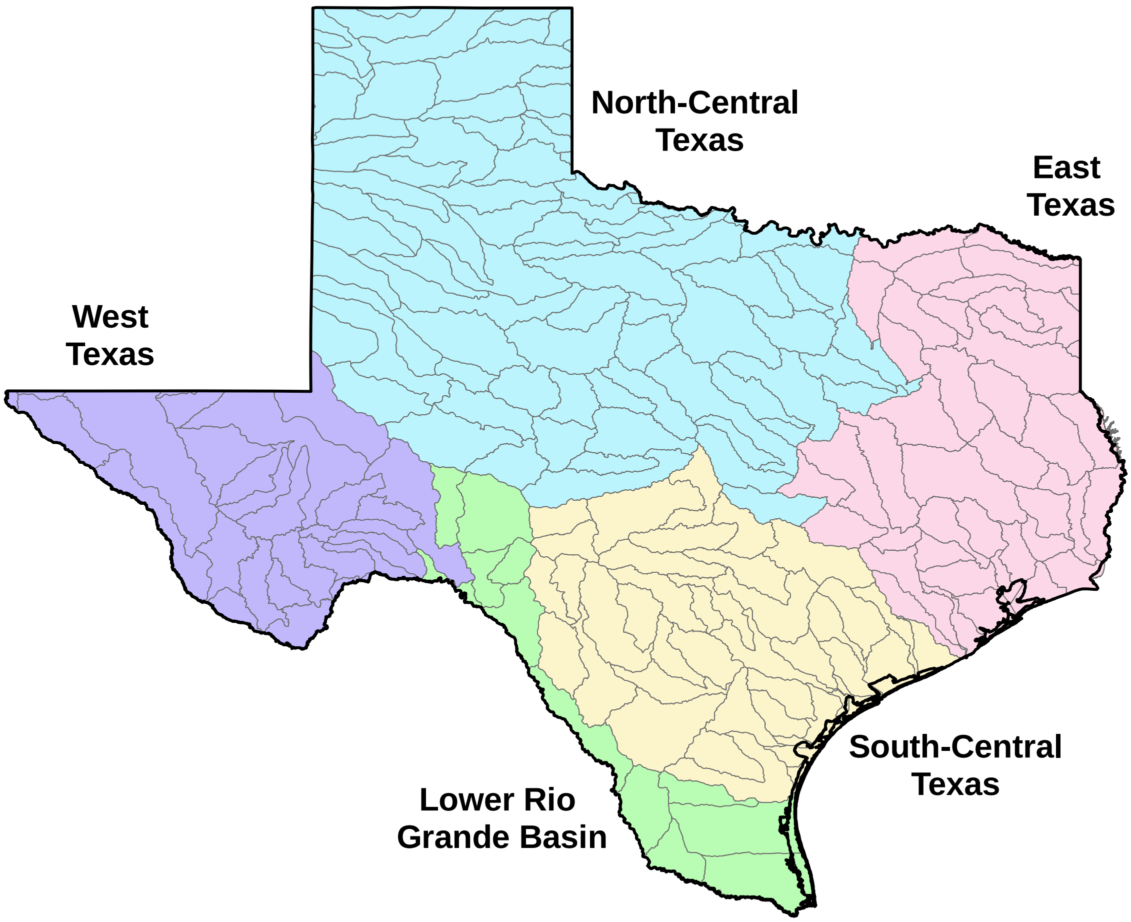

Figure 9. Map-based interpretation of the NRC text-based qualitative regionalization.

3.2.2 NRC Regions

The NRC (2005) regionalization is based on a series of qualitative distinguishing parameters, described below.

East Texas consists of the Lower Red, Lower Trinity, Lower Brazos, Navasota, Sabine and Neches river basins and is characterized by:

- 30 to 50 inches average precipitation
- Flat landscapes
- Clay-rich or sandy soils (sandy: Sabine, Neches)
- Flood pulses
- Dominant land use is agriculture

- High flow variations
- High turbidity (esp. Trinity, Brazos, Red)
- Soft, shifting substrate, large woody debris

South-Central Texas consists of the Blanco, Comal, Frio, Guadalupe, Lower Colorado, Nueces, Sabinal, San Antonio, and San Marcos river basins, including the Hill Country, and is characterized by:

- 10 to 40 inches average precipitation
- Infrequent flash floods
- Rocky, Edwards Plateau
- Clear and cool water
- Dominant land use is livestock grazing
- High base flow index

The Lower Rio Grande Basin consists of the Lower Rio Grande, Devils, Las Moras Creek, and San Felipe Creek river basins and is characterized by:

- 11 to 26 inches average precipitation
- Rio Grande occasionally reduced to series of isolated pools
- Rio Grande occasionally fails to reach Gulf of Mexico
- Dominant land use is irrigated row cropping (Lower Rio Grande) and livestock grazing (elsewhere)
- Stressed aquatic biota

West Texas consists of the Middle Rio Grande and Pecos river basins and is characterized by:

- 8 to 16 inches average precipitation
- High salinity in Pecos
- Dominant land use is livestock grazing

North-Central Texas consists of the Canadian, Upper Brazos, Upper Colorado, Upper Red, and Upper Trinity river basins and is characterized by:

- 15 to 28 inches average precipitation
- Occasional severe droughts
- Clay-rich soils
- Flood pulses
- Dominant land use is agriculture
- High flow variations (drought/flood) (NRC 2005)

A summary of the qualitative variables used in the NRC regionalization, grouped by discipline, can be found in Table 3.

Table 3. Summary of NRC regionalization variables.

Water Quality	Climatology	Hydrology & Hydraulics	Geomorphology & Physical Processes	Biology
Water temperature	Mean annual precipitation	Flow variability	Slope	Community stress
Turbidity		Flow pulses	Soil texture	
Salinity		Baseflow index	Land use	
		Longitudinal connectivity	Channel substrate	
			Channel mesohabitat (large woody debris)	

3.3 Thematic Layers

3.3.1 DISTINGUISHING PARAMETERS

Based on a review of stream classification literature, discussions with stakeholders and peers, and a review of available data, a series of quantitative parameters were selected for evaluation in the stream classification system (Table 4). These parameters were chosen as broad indicators of the river environment encompassing multiple disciplines. Their selection was based on data availability and perceived relevance to the ecological environment.

Table 4. Summary of quantitative variables.

Water Quality	Climatology	Hydrology & Hydraulics	Geomorphology & Physical Processes	Biology[1]
Water temperature	Mean annual precipitation	Mean annual streamflow	Channel bed slope	--
Dissolved oxygen	Mean annual temperature	Mean annual velocity	Basin percent sand	
pH	Mean annual potential evapotranspiration	Baseflow index (BFI)	Basin percent silt	
Specific conductance		Percent of zero flow days	Basin percent clay	
Total suspended solids		Flow variability	Substrate	

1. Biologic data were not incorporated into the current version of the stream classification system; refer to the Biology section below for discussion.

4. STREAM CLASSIFICATION SYSTEM INTEGRATED DATA

4.1 Foundation: Hydrography

4.1.1 NHDPLUS

The foundation of the proposed classification system is the NHDPlus hydrography dataset. The hydrography dataset is the mapped surface water system, often thought of as the 'blue lines' on a map (Maidment 2002). NHDPlus is an improved version of the USGS's National Hydrography Dataset (NHD) Medium Resolution (1:100,000 scale) and had been jointly developed by USGS, the U.S. Environmental Protection Agency (EPA), and Horizon Systems, Inc. as a contractor to EPA. NHDPlus is "an integrated suite of application-ready geospatial data sets that incorporate many of the best features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), the National Land Cover Dataset (NLDC), and the Watershed Boundary Dataset (WBD). The NHDPlus consists of nine components:

- Greatly improved 1:100K National Hydrography Dataset (NHD)
- A set of value added attributes to enhance stream network navigation, analysis and display
- An elevation-based catchment for each flowline in the stream network
- Catchment characteristics
- Headwater Node Areas
- Cumulative drainage area characteristics
- Flow direction, flow accumulation and elevation grids
- Flowline min/max elevations and slopes
- Flow volume & velocity estimates for each flowline in the stream network" (Horizon Systems 2007)

The integration of watershed and land surface data in NHDPlus represents a leap forward in the potential for the analysis of freshwater systems. Also, NHDPlus allows the user to map streams by flow size, thus enabling an at-a-glance understanding of the hydrologic flow pattern of the landscape (Figure 10).

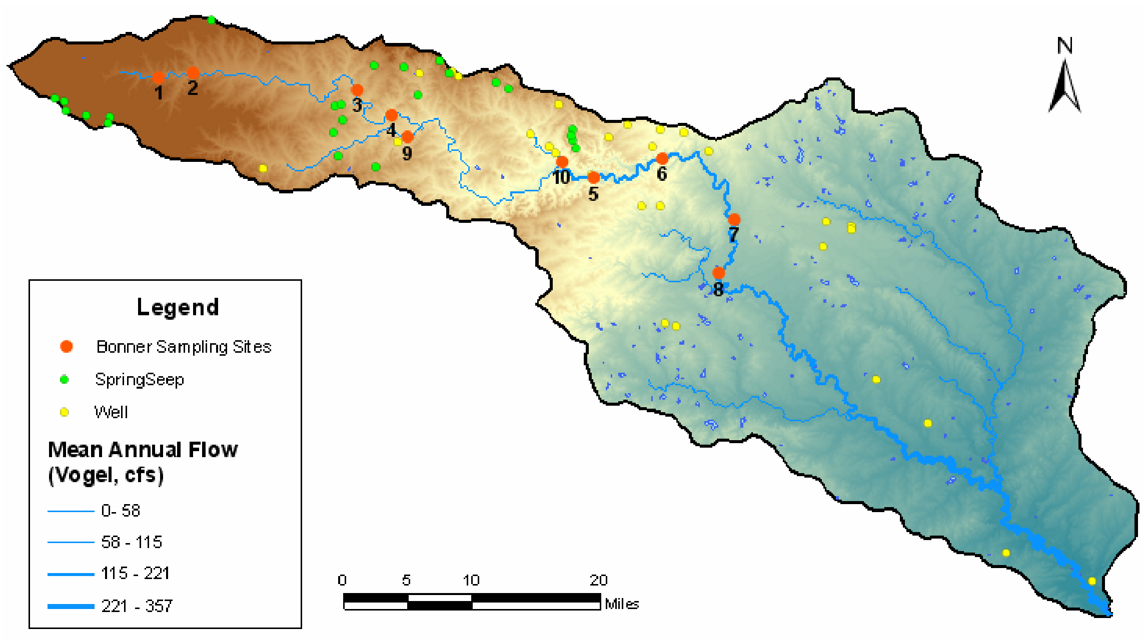

Figure 10. Example representation of elevation data (brown to green color ramp) and streamflow data (blue lines of varying thickness).

4.1.2 NHDPlus Spatial Representation

NHDPlus Regions are subdivided into Production Units to allow for easier extraction, file storage, and manipulation of the data (Figure 11 and Figure 12). The Production Units differ slightly from the major river basins of Texas (Figure 13).

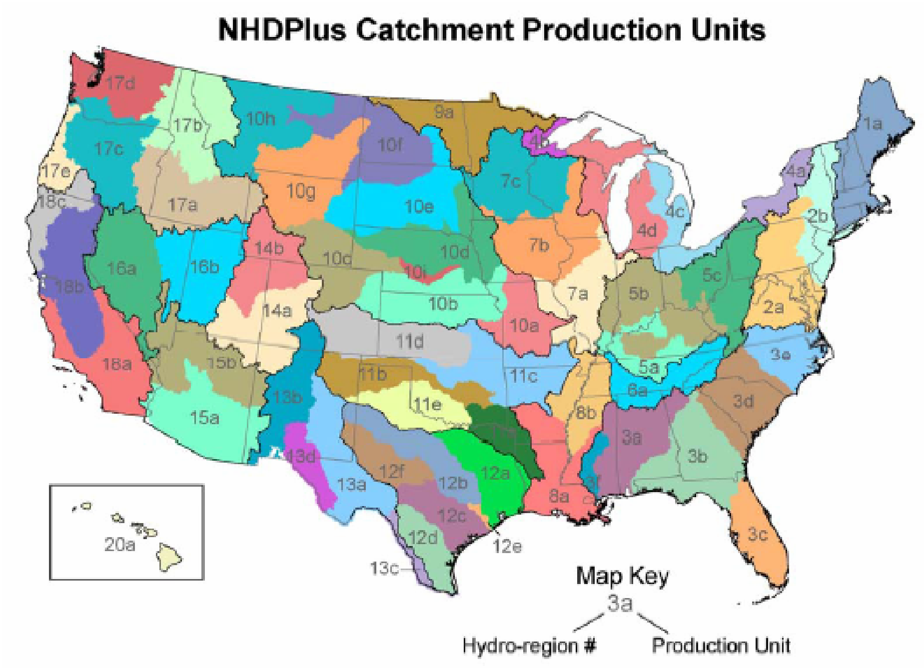

Figure 11. National NHDPlus Production Units.

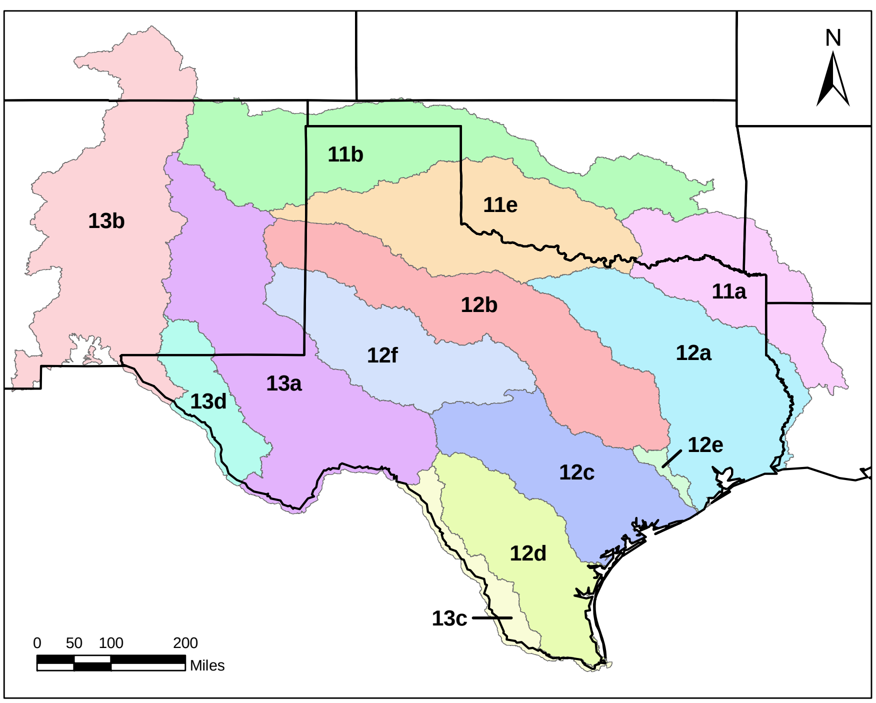

Figure 12. NHDPlus Production Units contributing flow to Texas waterways.

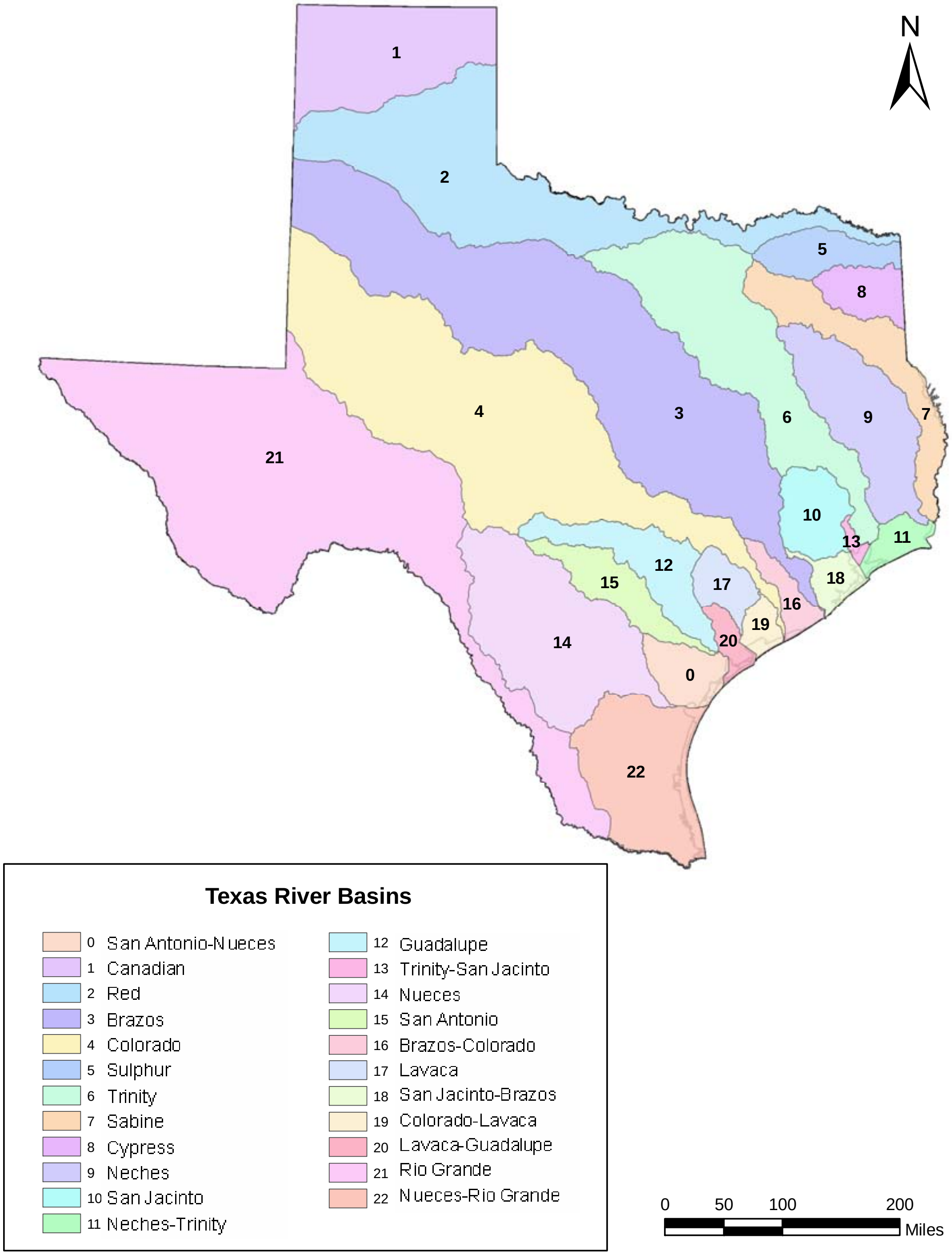

Figure 13. Major river basins of Texas.

NHDPlus has a hierarchy of nested drainage areas based on the United States Geologic Survey's Hydrologic Unit system (Figure 14) (Seaber et al 1987).

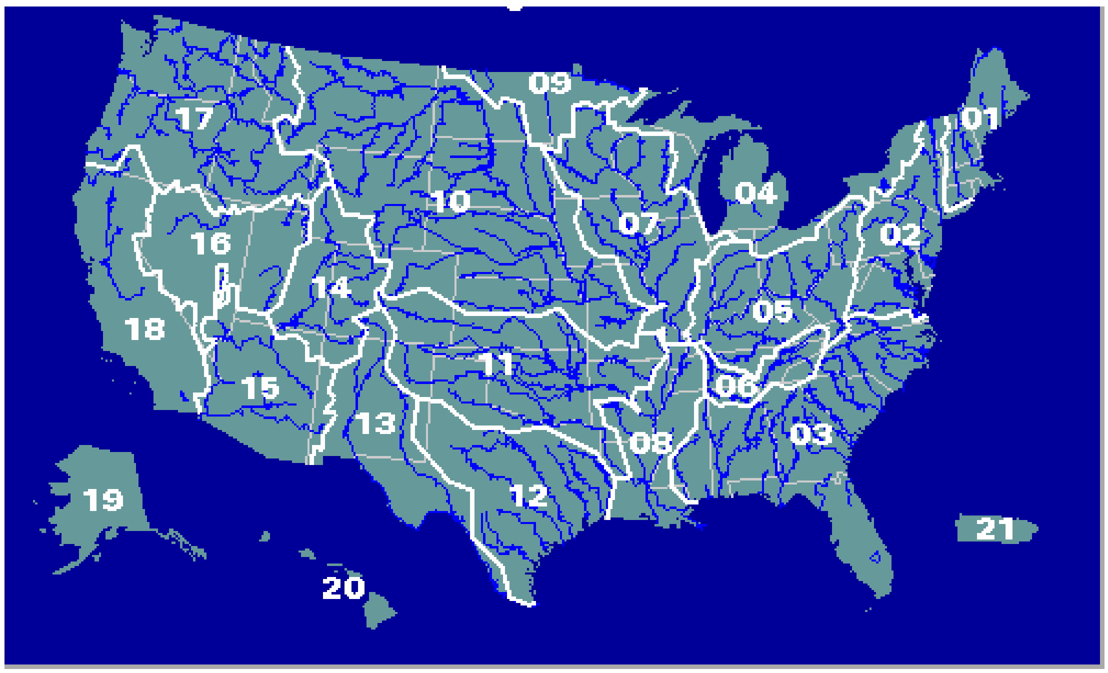

Figure 14. USGS Hydrologic Regions.

The top-most level of NHDPlus classification, NHDPlus Regions, are analogous to USGS Hydrologic Regions; there are 18 in the contiguous U.S. and one each for Alaska, Hawaii, and Puerto Rico for a total of 21 (Table 5).

Table 5. USGS and NHDPlus Hydrologic Units.

USGS			**NHDPlus**		**Mean Area (km^2)**
Hydrologic Units	**Count**	**Example**	**Hydrologic Units**	**Count**	
Hydrologic Region	21	12 – Texas Gulf	Region	21*	415,000
-	-	-	Production Unit	61*	130,000
Subregion	222	1210 – Central Texas Coastal	Subregion	N/A**	-
Accounting Unit	352	121002 – Guadalupe Basin	Watershed	N/A**	-
-	-	-	Subwatershed	N/A**	-
-	-	-	Basin	N/A**	-
Cataloging Unit	2150	12100203 – San Marcos, Texas	Subbasin	2117*	3,700
-	-	-	Catchment	2,614,642	3.0

*NHDPlus for Alaska and Puerto Rico is currently in progress and thus not included in the counts.

**Empty, but maintained within the NHDPlus schema as placeholders.

4.1.3 TEXAS HYDROGRAPHY

There are 211 NHDPlus subbasins (i.e., 8-digit HUCs) which lie wholly or partly within the boundaries of Texas, with an average area of approximately 3,300 square kilometers (Figure 15 and Figure 16); these 211 subbasins were used as the base unit for the stream classification system.

Figure 15. Subbasins of Texas.

Attributes of Named_SubBasins_Project

OBJECTID *	HUC	HUC_MAJOR1	BASIN_NAME	REG	SUBR	ACCT	CAT	STATE	NAME	ID	Area_SQKM
152	13040204	33	Rio Grande	13	4	2	4	TX	Terlingua	167	3302.61
153	13040303	33	Rio Grande	13	4	3	3	TX	Dry Devils	40	1866.5
154	12100201	36	Guadalupe	12	10	2	1	TX	Upper Guadalupe	182	3745.11
155	13040208	33	Rio Grande	13	4	2	8	TX	Reagan-Sanderson	140	1406.5
156	12070104	26	Brazos	12	7	1	4	TX	Lower Brazos	74	4230.65
157	13040302	33	Rio Grande	13	4	3	2	TX	Lower Devils	80	2293.08
158	12100203	36	Guadalupe	12	10	2	3	TX	San Marcos	154	3518.2
159	13040212	33	Rio Grande	13	4	2	12	TX	Amistad Reservoir	2	5105.37
160	12040201	35	Neches-Trinity	12	4	2	1	TX	Sabine Lake	145	2345.66
161	12040203	37	Trinity-San Jacint	12	4	2	3	TX	North Galveston Bay	125	1010.66
162	12110102	38	Nueces	12	11	1	2	TX	West Nueces	199	2339.71
163	12110101	38	Nueces	12	11	1	1	TX	Nueces Headwaters	130	2113.96

Record: 0 Show: All Selected Records (0 out of 211 Selected) Options

Figure 16. NHDPlus subbasin attributes.

4.2 Water Quality

4.2.1 TCEQ TRACS

An understanding of water quality (here synonymously used with the term "water chemistry") is important to determine the suitability and quality of riverine habitat as well as to assess the level of impairment of a water body. Thus, the entire surface water quality database for Texas was acquired at CRWR for incorporation into this stream classification system. The TCEQ Regulatory Activities and Compliance Systems (TRACS) Surface Water Quality Monitoring (SWQM) system includes 7.5 million records from 733,000 sampling events at 7,138 stations measuring 1,072 parameters from 1968 through August 14, 2006 (Figure 17) (TCEQ 2007).[1]

Water quality parameters included here (and all parameters in general) were selected to provide a synoptic picture of stream type and to minimize, as much as possible, the consideration of anthropogenic effects. For water quality, the intent is not to measure pollution or human impact explicitly. However, given the current and historic use of Texas waterways, it is not feasible to separate out altered conditions from natural conditions for water quality without sophisticated modeling and data reconstruction techniques.

[1] Data are still being collected at present. However, the TCEQ is in the process of transitioning the TRACS SWQM database into a new format, SWQMIS. Data collected since August 2006 are only being stored in the new system.

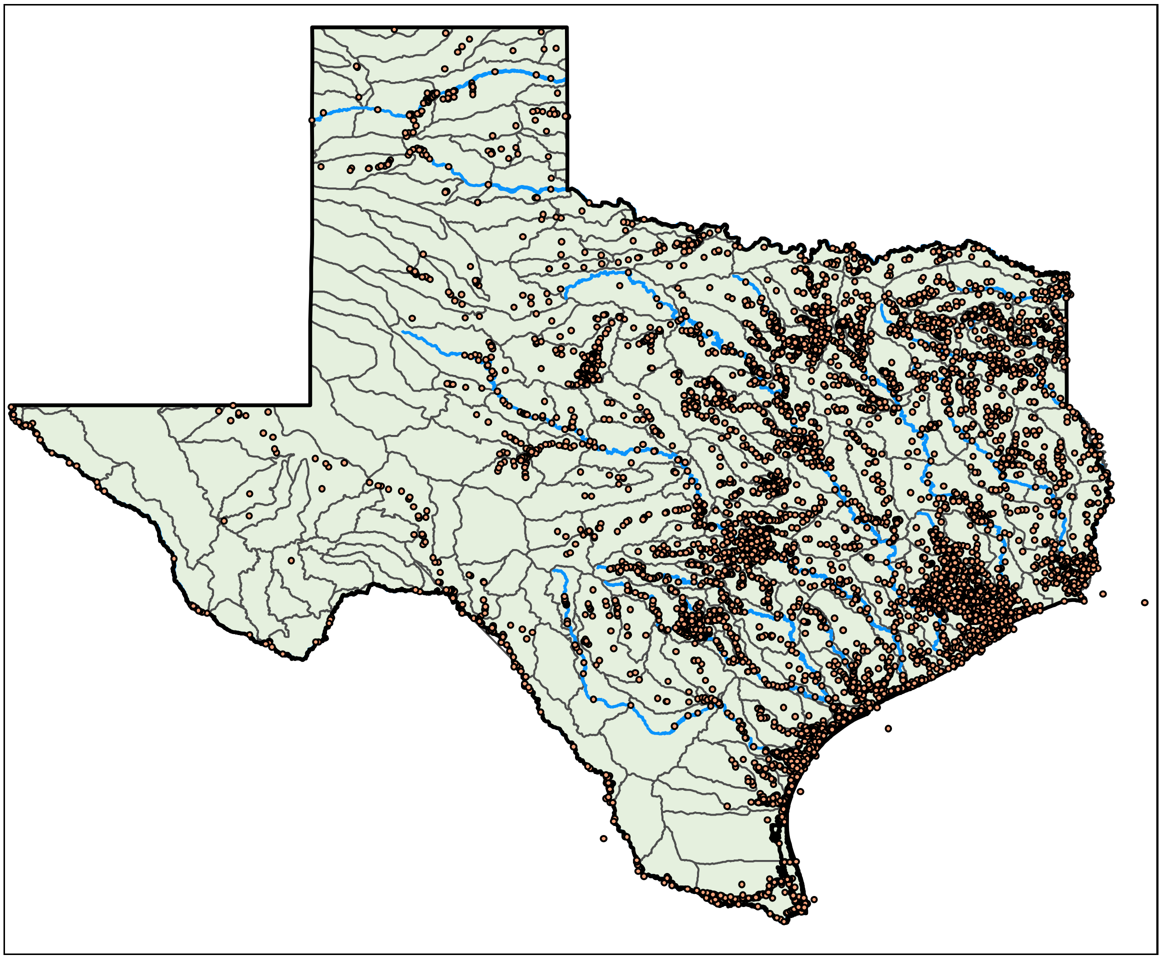

Figure 17. TRACS SWQM stations, 1968-2006.

4.2.2 WATER QUALITY VARIABLES

The water quality parameters considered here include:

- water temperature,
- dissolved oxygen,
- pH,
- specific conductance, and
- total suspended solids (i.e., total nonfiltrable residue)

and rank as the first, second, third, fourth, and seventh most frequently sampled parameters in the SWQM database (Figure 18 and Table 6). Water temperature is measured and recorded in both degrees Celsius and Fahrenheit (ranked #1 and #10 with EPA Storage and Retrieval (STORET) codes 00010 and 00011, respectively). An examination of the data has revealed that the majority of the Fahrenheit data was collected prior to 1986 and is recorded redundantly with Celsius data; that is, both records for water temperature from a given sampling event carry the same TagID identification.

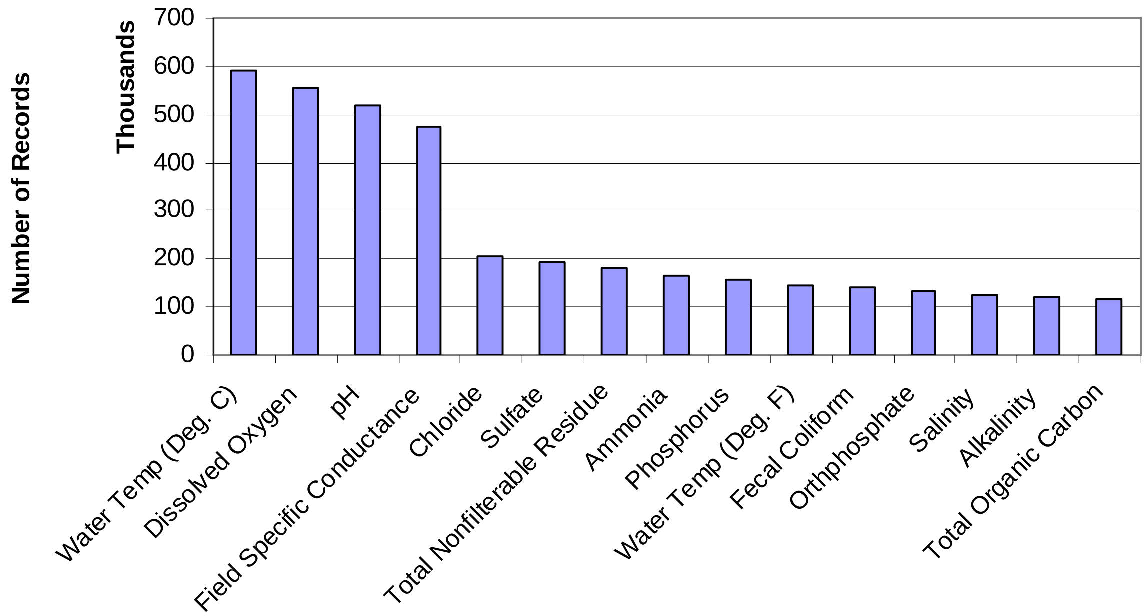

Figure 18. SWQM top fifteen parameters by result (Jantzen 2007).

Table 6. Water quality parameters used in the stream classification system.

WQ Parameter	STORET Code
Water Temperature	00010
Specific Conductance[1]	00094
Dissolved Oxygen	00300
pH	00400
Total Suspended Solids[2]	00530

1. Specific conductance considered in lieu of salinity (STORET 00480), eliminated from consideration due to poor spatial and temporal coverage.
2. TSS considered in lieu of turbidity (as measured by STORET 82079, field measure; 82078, lab measure; or 61028 unfiltered) due to poor spatial and temporal coverage.

The SWQM database at CRWR is stored in both Microsoft Access and Structured Query Language (SQL) Server formats; the former is only 920 megabytes in size while the latter is 7.22 gigabytes. A series of SQL queries were written in Access to extract water quality data by parameter and then aggregate it by subbasin. That is, the 8-digit HUC code for each of the 7,138 stations was appended to the sample attribute (Event) table in ESRI ArcMap software via the spatial join tool, the data were extracted from the Results table by station, and the data for the entire period of record from all stations within a given subbasin were averaged together to create a single value for each subbasin for each parameter. Of the 211 subbasins in Texas, water quality data for each of the five parameters of interest was available for 156 subbasins for DO and water temperature, 155 for pH and specific conductance, and 148 for total suspended solids (Figure 19, Figure 20, Figure 21, Figure 22, Figure 23, and Figure 24). Data was also available for each of the five parameters of interest in the Gulf of Mexico.

Dissolved oxygen records were filtered to include only samples taken at a depth less than 1.6 meters (5.25 feet) to eliminate redundant records from depth profile sampling at the same site and time.

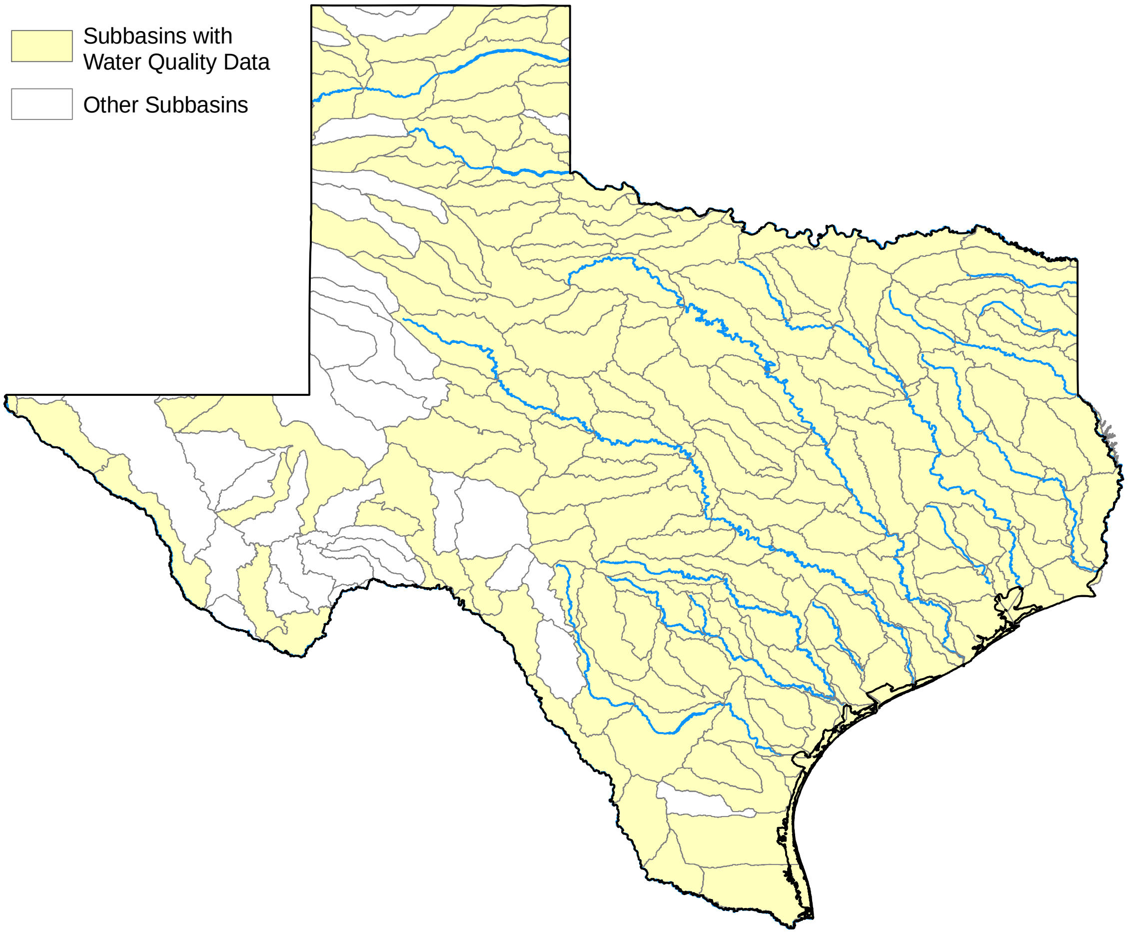

Figure 19. Subbasins with any water quality data in TRACS, 1968-2006.

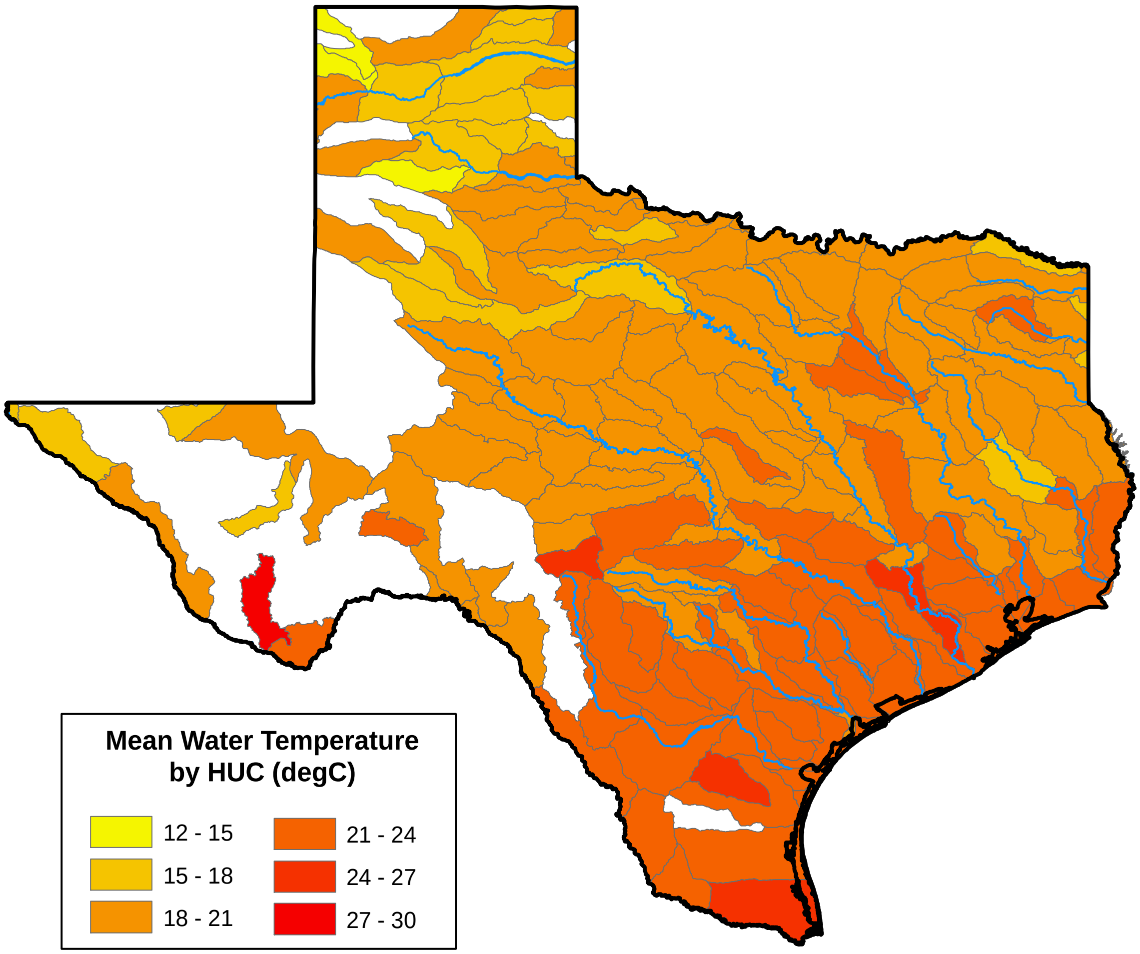

Figure 20. Mean water temperature (in degrees C) by subbasin.

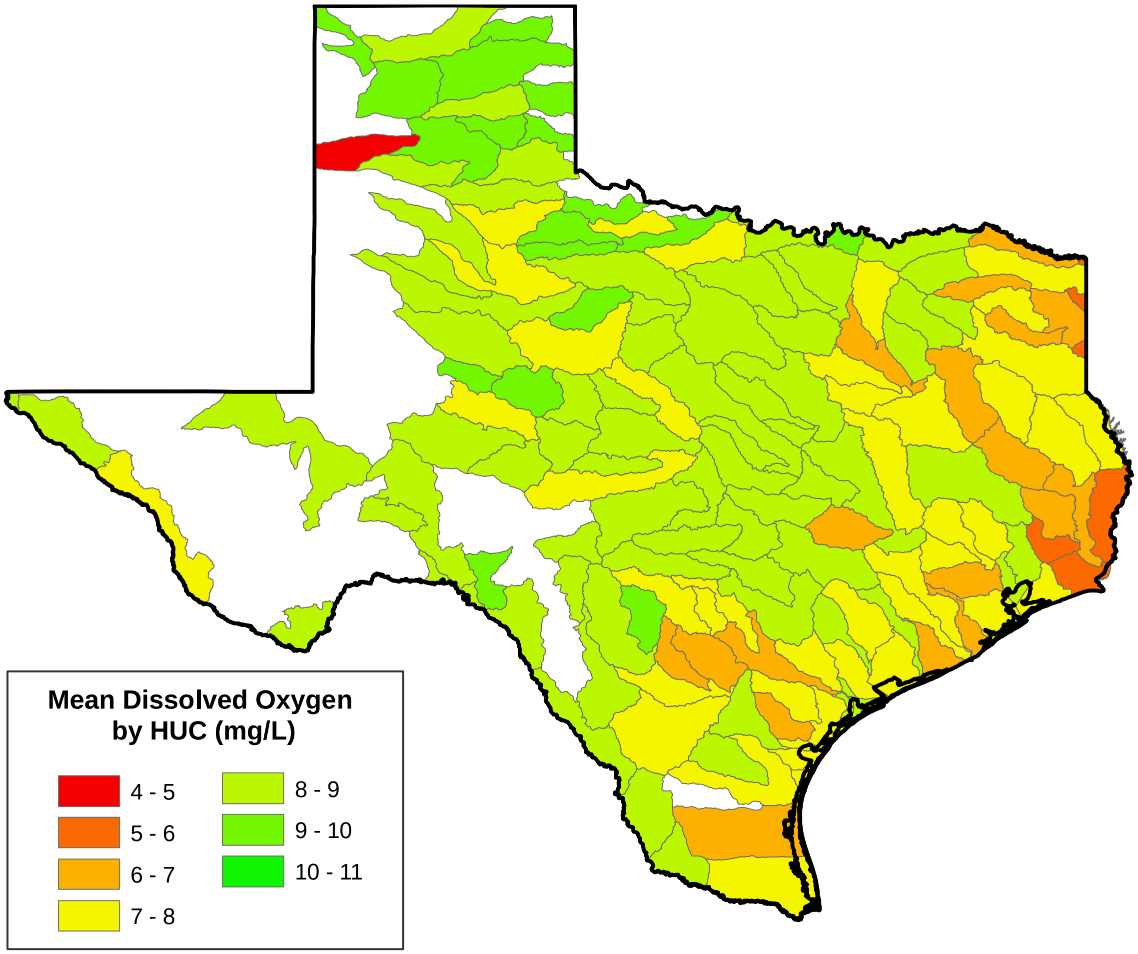

Figure 21. Mean dissolved oxygen by subbasin.

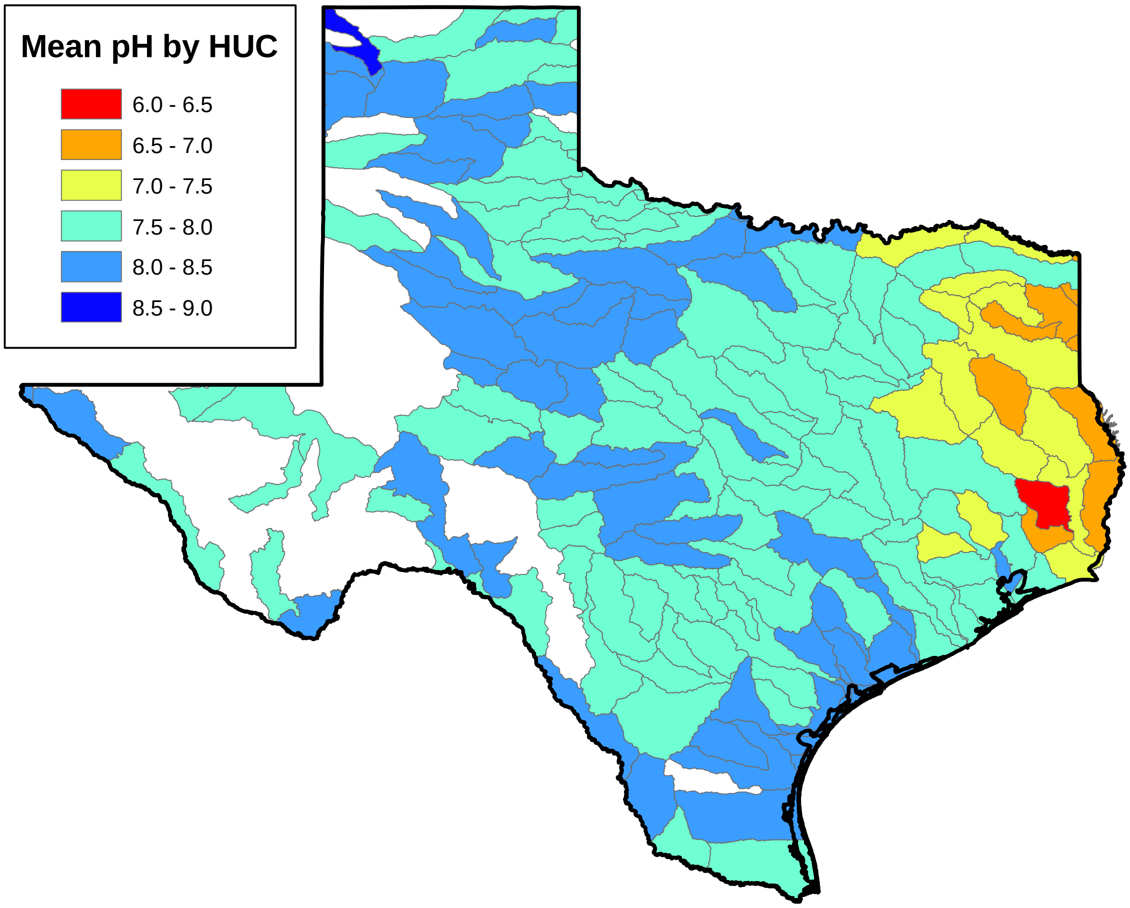

Figure 22. Mean pH by subbasin.

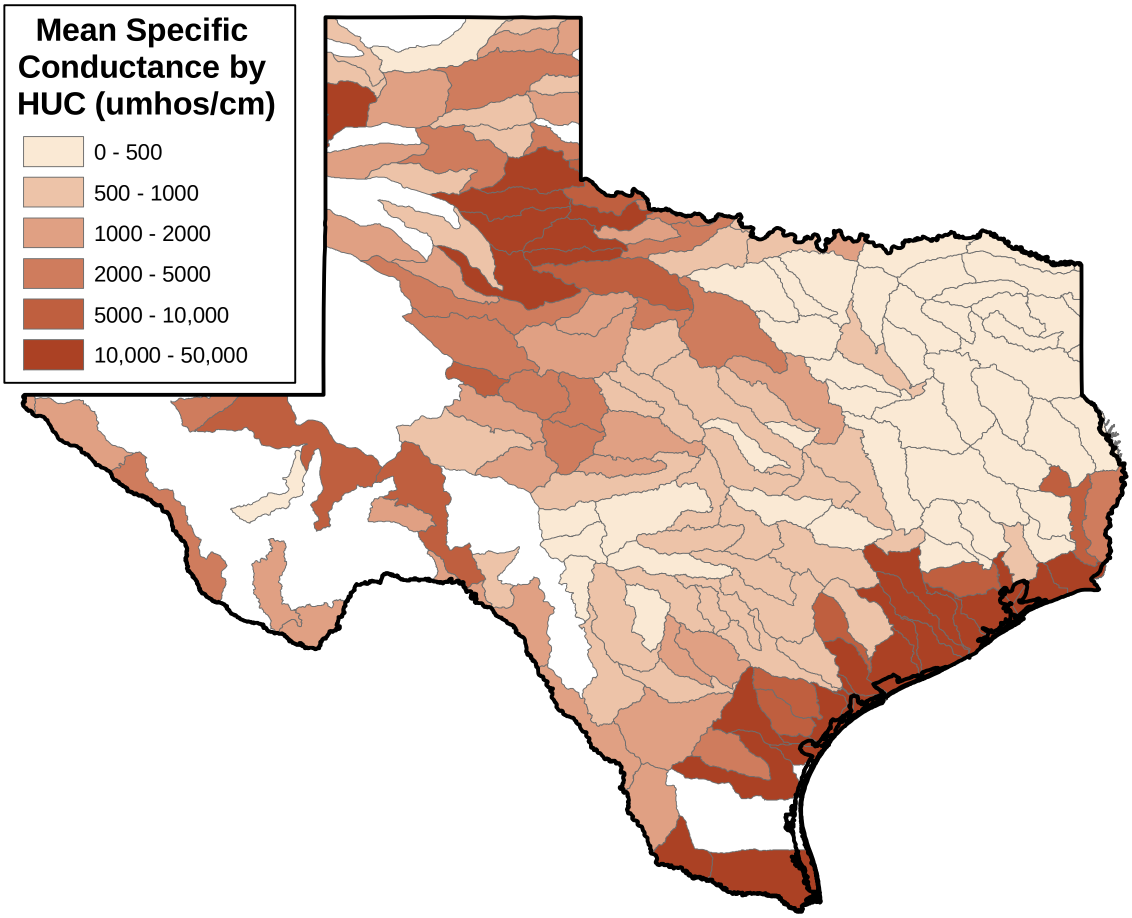

Figure 23. Mean specific conductance by subbasin.

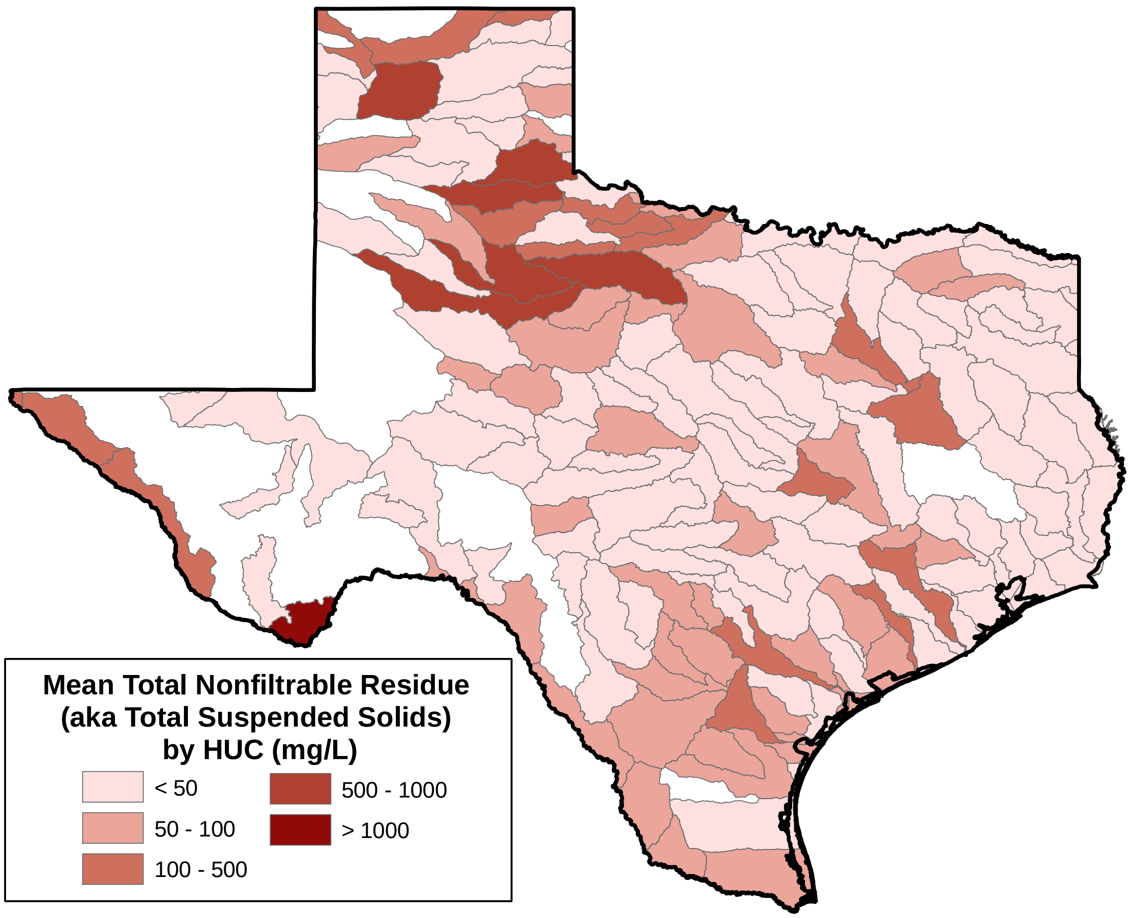

Figure 24. Mean total nonfiltrable residue (i.e., total suspended solids) by subbasin.

As can be seen in the above figures, Texas streams exhibit, on average:

- Warmer temperatures to the south and along the coast
- Lower dissolved oxygen at the coast and in east Texas
- Higher acidity in east Texas
- Higher specific conductance (~salinity) along the coast (includes tidal systems), in the Pecos and Red River basins
- Higher total suspended solids (TSS) in the Red River and Brazos River basins.

Water quality data were examined for redundancy and correlation using the square of the Pearson product-moment correlation method (R^2), also known as the coefficient of determination. R-squared ranges from 0 to ±1 and describes the percent of variation in Y that can be explained by variation in X.

Each water quality parameter was tested against every other for a total of 10 tests. In general, one parameter could explain only 0 to 11 percent of variation in each other parameter except for dissolved oxygen, where variations in DO were able to explain 28% of the variation in pH (Figure 25). Results of this analysis indicate that the level of redundancy between water quality variables chosen is low. This implies that it is appropriate to include all these variables in the classification system, as each describes different components of stream type and represent different sources of control and variation.

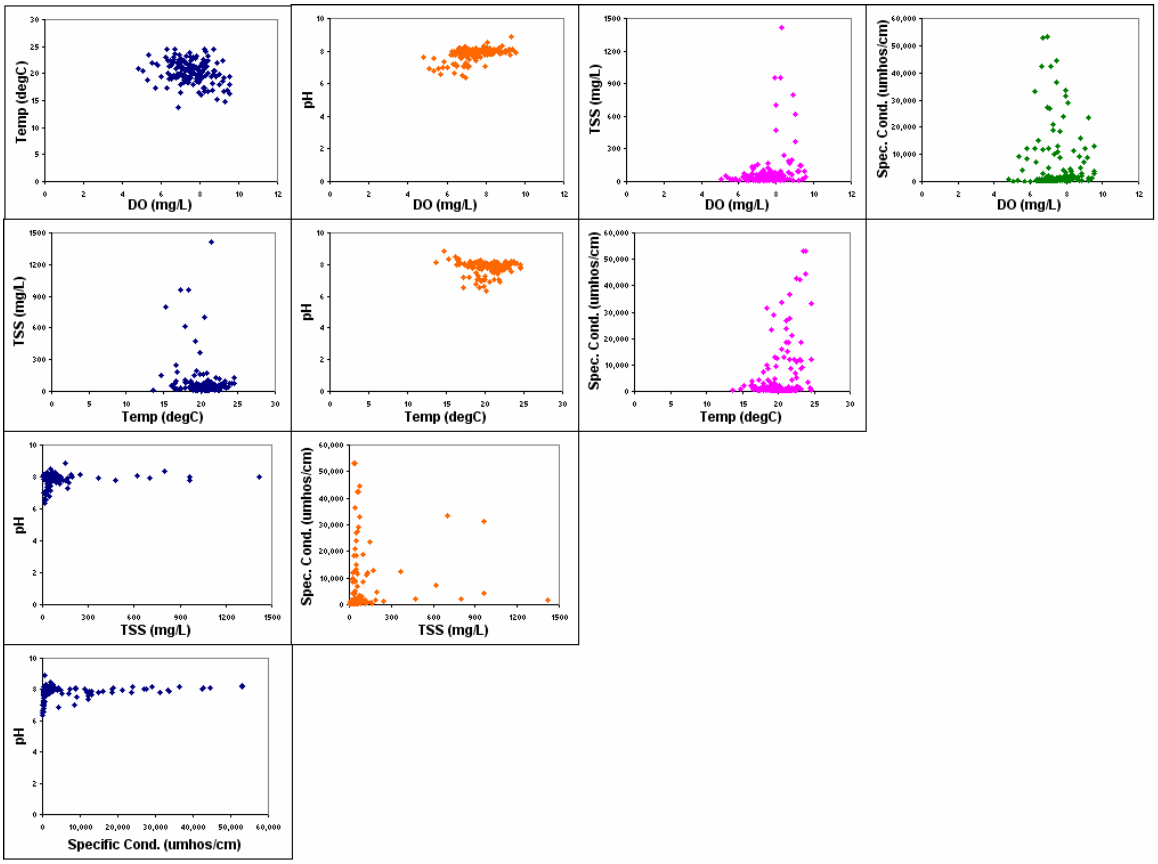

Figure 25. Tests for correlation between water quality parameters, grouped by: DO (top four), temperature (three), TSS (two), and specific conductance (one). Note: scales and correlated variable are not important in this case; plots are simply meant to depict scatter in the data.

4.3 Climatology

4.3.1 Data Sources

Climatology is a driver of habitat and hydrology on a macro-scale. In this project, mean annual temperature, mean annual precipitation, and mean annual potential evapotranspiration (PET) were variables considered for their classification potential. Data for average annual precipitation and average annual temperature are included in the CatchmentAttributesTempPrecip table within NHDPlus and are derived from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Group

2006). PET data were obtained from the Texas Evapotranspiration Network from the Irrigation Technology Center at the Texas Water Resources Institute of the Texas A&M University System (ITC 2005).

4.3.2 Climatology Variables

Precipitation exhibits a strong east-west gradient across Texas, with eastern regions being much wetter than arid western regions (Figure 26). Temperature exhibits a strong gradient as well, with south Texas and the lower elevation coastal plain being warmer than north Texas and the higher elevation areas of the panhandle and west Texas (Figure 27).

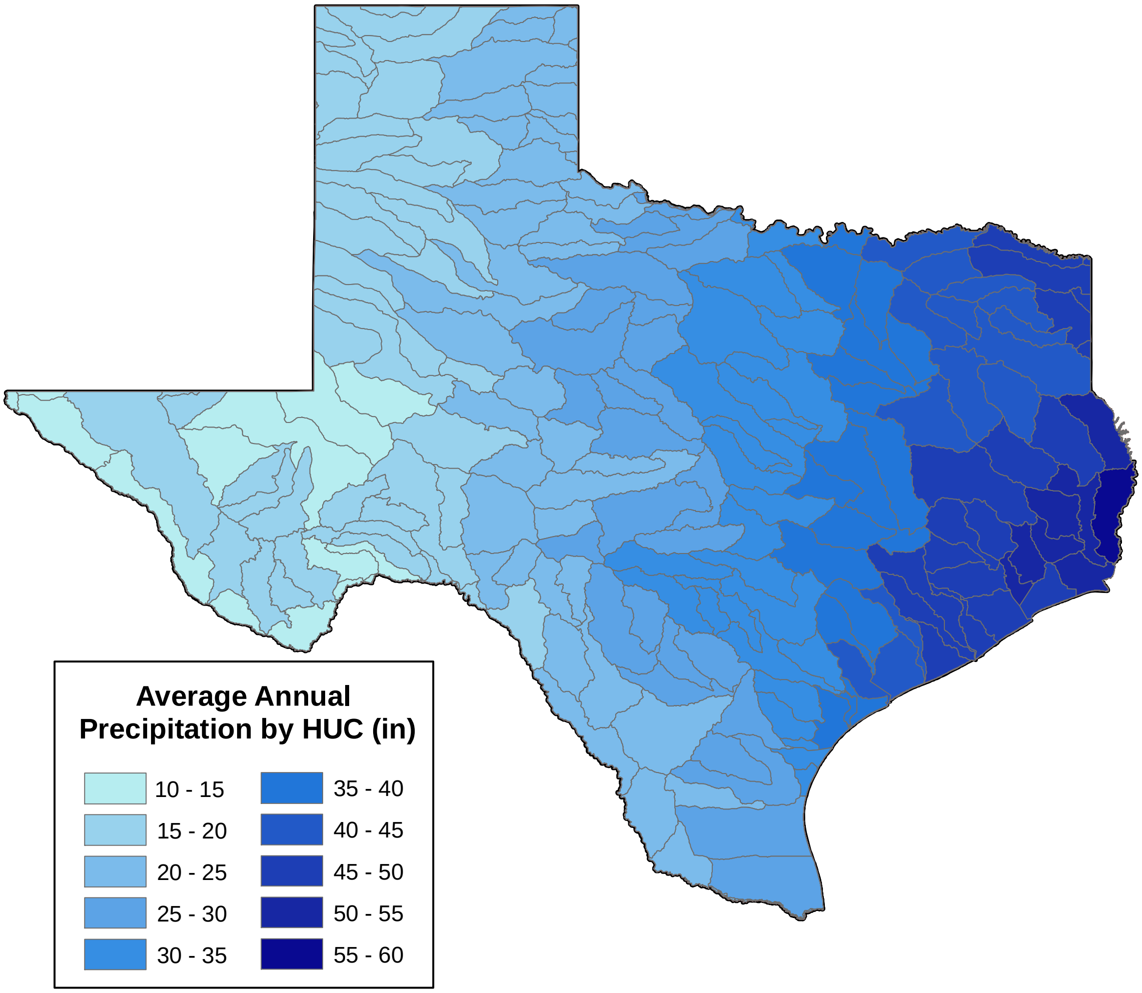

Figure 26. Mean annual precipitation by subbasin.

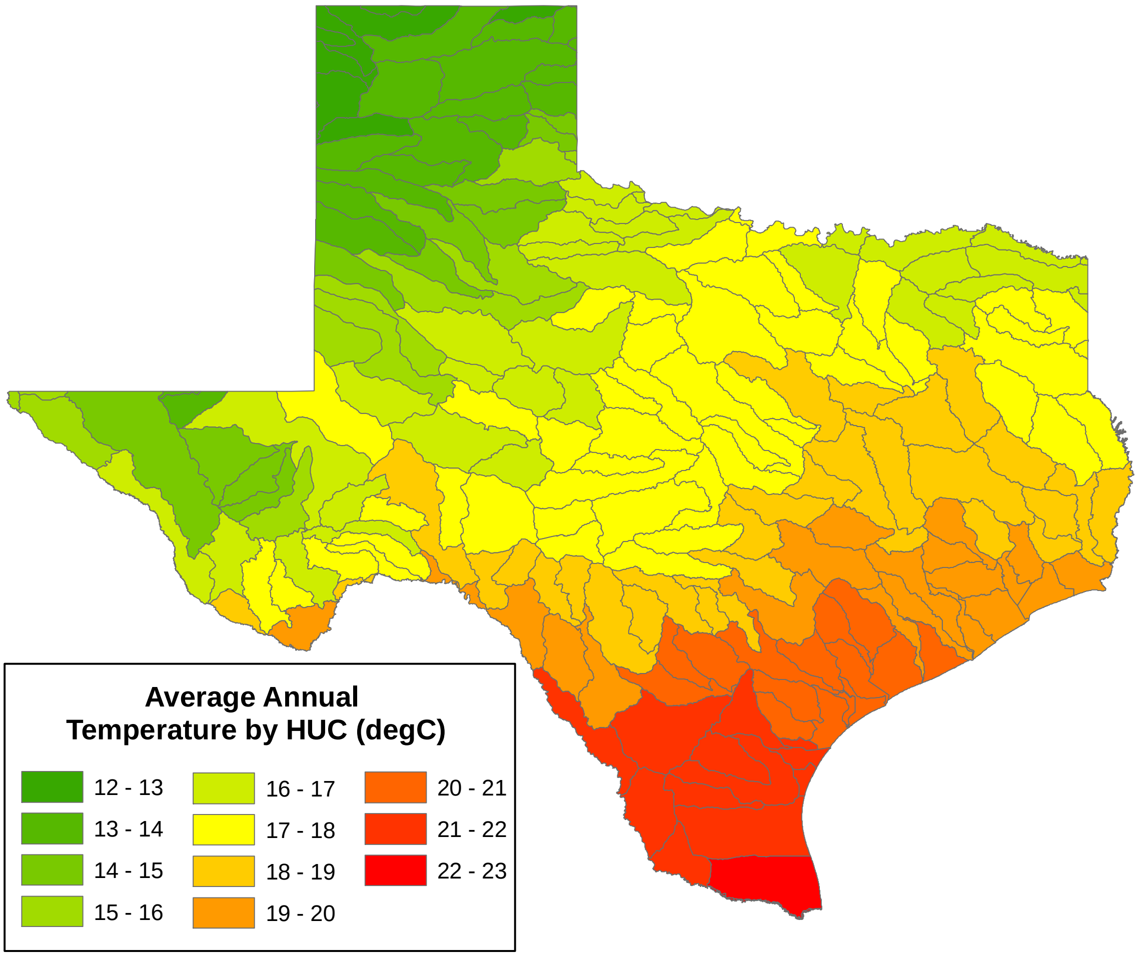

Figure 27. Mean annual temperature by subbasin.

PET data consist of monthly average values for 19 selected Texas cities calculated from National Weather Service data with periods of record ranging from 26 to 99 years and an average of 56 years (Table 7). Mean annual PET data were interpolated across the State using the inverse distance weighting method and averaged by HUC; for the northernmost HUCs in the panhandle of Texas (the 'white space' at the top of Figure 28), PET values were extrapolated by assuming similarity to the PET values calculated for the City of Amarillo (Figure 28 and Figure 29). In general, PET is higher in arid west Texas and lower along the more humid coast and east Texas regions.

Table 7. Average monthly PET at selected Texas cities (from ITC 2005).

Average Monthly ETo (PET) (inches/month)													
City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Abilene	2.08	2.57	4.14	5.48	6.47	7.65	8.36	7.46	5.48	4.21	2.67	2.08	**58.65**
Amarillo	1.84	2.27	3.73	5.06	5.89	7.51	8.08	7.29	5.61	4.05	2.4	1.78	**58.65**
Austin	2.27	2.72	4.34	5.27	6.39	7.15	7.22	7.25	5.57	4.38	2.74	2.21	**57.51**
Brownsville	2.65	3.03	4.48	5.17	6.03	6.32	6.68	6.65	5.21	4.34	3.01	2.59	**56.16**
College Station	2.2	2.71	4.22	5.2	6.25	6.89	7.1	6.85	5.6	4.3	2.8	2.2	**56.32**
Corpus Christi	2.42	2.95	4.28	5.17	5.95	6.43	6.68	6.65	5.21	4.34	3.01	2.59	**55.68**
Dallas/Ft. Worth	2.0	2.46	3.96	5.14	6.21	7.06	7.40	7.25	5.49	4.19	2.59	2.10	**55.85**
Del Rio	2.47	3.01	4.76	6.01	6.98	7.41	7.57	7.41	5.77	4.35	2.91	2.36	**61.01**
El Paso	2.74	3.53	6.07	8.19	9.83	11.12	9.19	8.94	7.69	5.89	3.58	2.49	**79.26**
Galveston	2.2	2.6	4.1	5.0	6.11	6.6	6.2	6.0	5.5	4.2	2.8	2.3	**53.61**
Houston	2.36	2.83	4.32	5.01	6.11	6.57	6.52	6.08	5.57	4.28	2.9	2.35	**54.9**
Lubbock	2.35	2.63	4.41	5.53	6.93	7.73	7.63	7.2	5.54	4.19	2.61	2.33	**59.08**
Midland	2.2	2.78	4.46	5.91	7.21	8.2	9.23	8.62	6.95	4.31	2.78	2.16	**64.81**
Port Arthur	2.25	2.63	3.95	5.09	6.12	6.6	5.81	5.61	5.46	4.18	2.76	2.23	**52.69**
San Angelo	2.88	3.13	5.31	7.01	8.48	9.16	9.29	8.49	6.60	5.08	3.37	2.54	**71.34**
San Antonio	2.42	2.9	4.42	5.47	6.47	6.97	7.31	6.99	5.64	4.44	2.85	2.36	**59.93**
Uvalde	2.44	2.95	4.62	5.85	6.7	7.21	7.5	7.31	5.7	4.4	2.89	2.36	**59.93**
Victoria	2.35	2.87	4.29	5.77	6.39	6.7	6.92	6.7	5.36	4.41	2.93	2.33	**57.02**
Waco	2.13	2.62	4.03	5.31	6.45	7.15	7.40	7.5	5.7	4..41	2.7	2.17	**54.05**
Weslaco	2.5	2.57	3.96	4.9	6.12	6.53	7.0	6.58	4.79	3.96	2.85	2.29	**54.05**
Wichita Falls	1.94	2.46	4.07	5.50	6.7	7.54	7.97	7.72	5.79	4.3	2.62	1.95	**58.56**

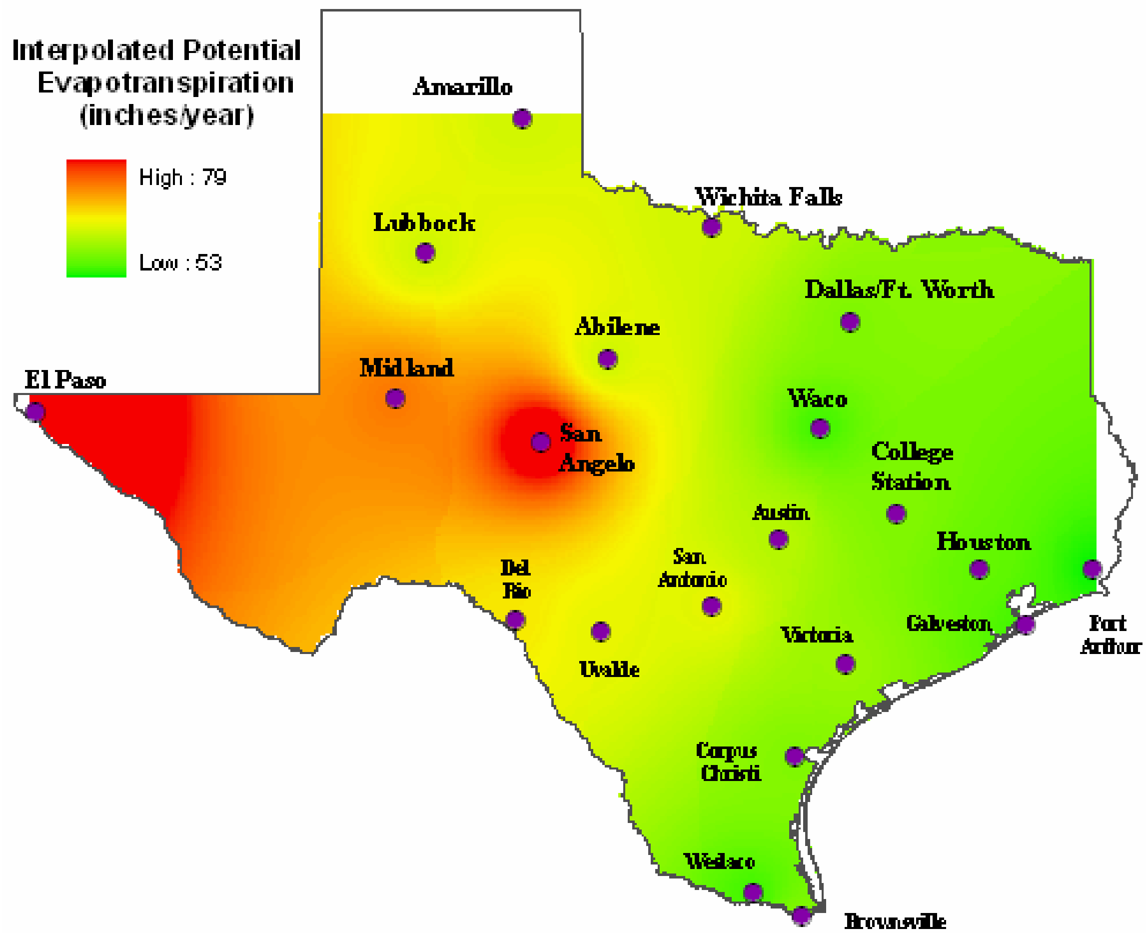

Figure 28. Interpolated mean annual PET.

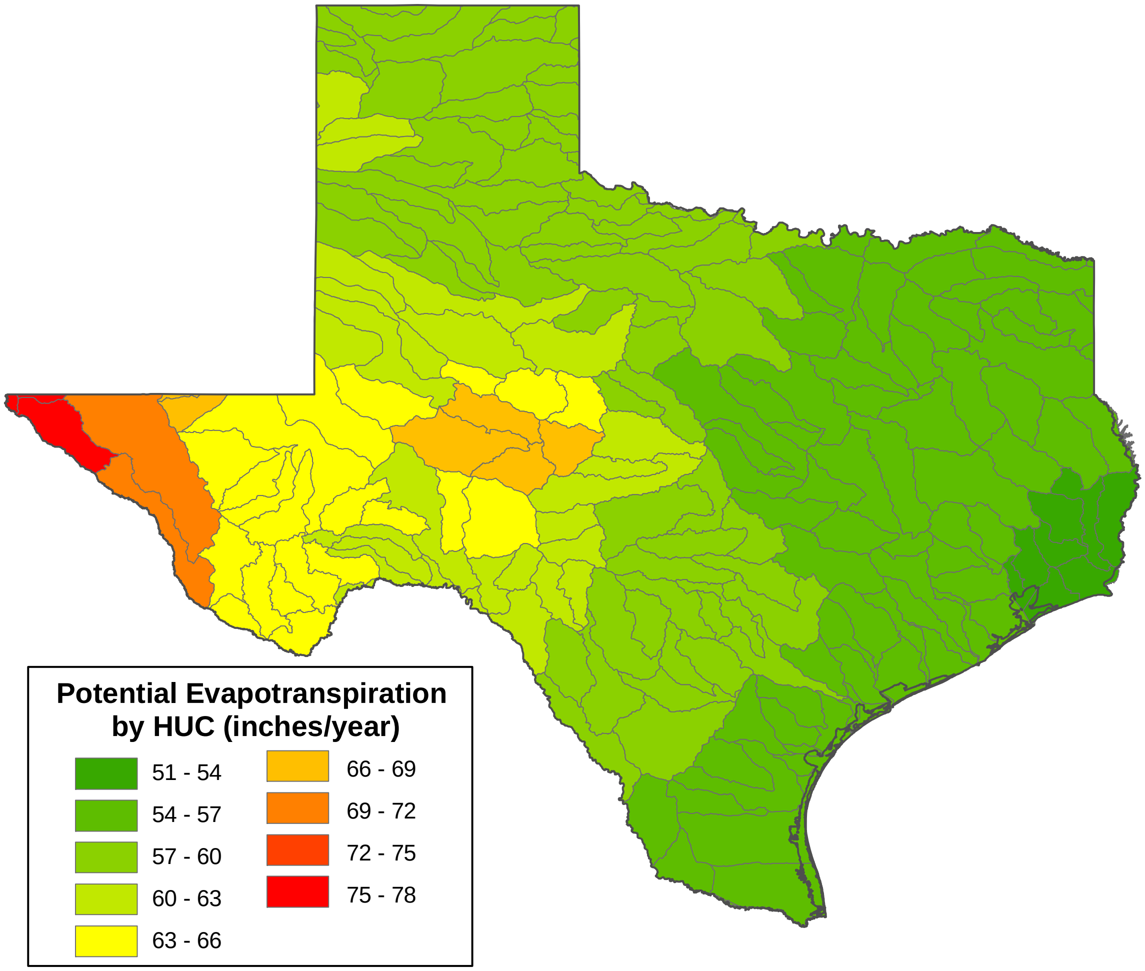

Figure 29. Mean annual PET by HUC.

4.4 Hydrology and Hydraulics

4.4.1 Data Sources

Hydrology is the ultimate controlling factor on riverine ecosystems and hydraulics is the physical manifestation of the movement of water within a river channel and its floodplain. The hydrology and hydraulics variables considered in this stream classification system include:

- Mean annual streamflow
- Mean annual stream velocity
- Base flow Index
- Percent of zero flow days
- Flow Variability, as expressed by the Interquartile Range (IQR).

The incorporation of mean annual streamflow (MAF) data into the NHD was one of the main motivating factors behind the creation of NHDPlus (USEPA and USGS 2006). In NHDPlus, three different methods are used to estimate average streamflow and the results from all three are included in the dataset. The Unit Runoff Method (UROM) (Research Triangle Institute 2001) and the Vogel Method (Vogel et al. 1999) are both used to calculate mean annual streamflow at the bottom of a flowline and the estimates generated by these two methods can be found in the FlowlineAttributesFlow attribute table. Similarly, one attribute of the StreamGageEvent layer is AVE, the average daily flow for the period of record at every USGS stream gage in NHDPlus. In contrast to the UROM and Vogel estimates which are calculated and reported at each flowline in NHDPlus, the average daily flow is only calculated and represented at stream gage point features. In addition, while the UROM and Vogel estimates are modeled streamflows for every stream reach in the United States, the average daily flow is calculated from actual data (USEPA and USGS 2006).

The UROM and Vogel methods both rely on the 1,338 national Hydro-Climatic Data Network (HCDN) gages. The HCDN subset of gages are selected from the USGS NWIS stream gage network because they are believed to be less affected by human activities and thus flow conditions recorded at these gages are likely more representative of natural conditions. The UROM method estimates a unit discharge for an ungaged site from a distance-weighted average of unit discharge from up to five HCDN gages within a 200-mile search radius. The unit discharge is then multiplied by the catchment area at each point of interest to generate an incremental streamflow, and the mean annual flow for each flowline in NHDPlus is calculated by summing these incremental flows. The Vogel method uses a log-log regression incorporating drainage area, precipitation, temperature, and multiple region-specific coefficients derived for 18 hydrologic regions of the country. Estimates of mean annual streamflow in NHDPlus are individually derived using the Vogel method at the bottom point of each flowline (Vogel et al. 1999, Research Triangle Institute 2001, USEPA and USGS 2006).

The average daily flow values stored in the StreamGageEvent layer were calculated from the USGS NWIS database. Approximately 23,000 stream gages nationwide were snapped to the NHD medium-resolution flowlines for use in NHDPlus. The flow statistics included in NHDPlus were calculated for the period of record for each streamflow gage from the date of first measurement through June 15, 2005 (USEPA and USGS 2006). The mean annual flow values included in this dataset were used in classification system here as they are believed to be more representative of actual streamflow conditions across the State and are calculated from measured data (as opposed to the modeled data from the UROM and Vogel methods).

Mean annual velocity (MAV) is another attribute in the NHDPlus FlowlineAttributesFlow table and is calculated from both MAF methods. MAV is estimated from regression analyses performed on hydraulic variables (drainage area, flowline slope, mean annual discharge, and discharge at the time of the measurement) from 980 time-of-travel studies representing 90 rivers in the United States. The resulting set of regression equations relates stream velocity to actual drainage area, dimensionless drainage area, streambed slope, actual discharge, and dimensionless relative discharge (Jobson 1996, USEPA and USGS 2006).

Base flow is another important control on habitat availability. Base flow is the portion of stream discharge that is not attributable to direct runoff from precipitation or snowmelt and is usually sustained by throughflow and groundwater flow; base flow can be thought of as the typical flow condition of a river in the absence of a rain event and ranges from 0 to 1 as the proportion of streamflow derived from base flow. Base flow data from the United States Bureau of Reclamation’s BFI program are included in NHDPlus in the StreamGage layer, including:

- BFIyrs: number of years of flow data used in the base flow index (BFI) calculation
- BFI_Ave: average annual base flow index
- BFI_Stdev: standard deviation of the annual base flow index

- GotBFI: flag indicating the presence/absence of BFI data.

Zero flow days are important in their role as a stressor on the aquatic ecosystem, both in their role in the lifecycles of native species and in controlling and managing non-native, invasive species. The percentage of zero flow days was calculated from the NHDPlus StreamGage layer by subtracting the total number of non-zero flow days (NDaysGT0) from the total number of days of flow data (NDays).

Similarly, variability of a flow regime is another important control in a riverine environment, here represented by the daily streamflow IQR. The IQR was calculated from the NHDPlus StreamGage layer by subtracting the 25th percentile of daily flow (P25) for the period of record from the 75th percentile (P75). Using these particular flows provides an understanding of the spread of daily flow data without being disproportionately affected by the extreme hydrologic events, either flood or drought, which often control the upper and lower flow quartiles.

The NHDPlus StreamGage layer contains 918 gages in Texas. Of these:

- 730 gages have greater than or equal to 1 year of daily flow data;
- 558 gages have greater than or equal to 10 years of daily flow data; and
- 427 gages have greater than or equal to 20 year of daily flow data.

The subset of 427 gages with at least 20 years of record was chosen for analysis. Twenty years is believed to be the minimum daily time-series record to sufficiently represent long-term hydrologic conditions for the purposes of the study and to minimize the importance of extended hydroclimactic aberrations.

4.4.2 HYDROLOGIC AND HYDRAULIC VARIABLES

The mean annual flow was divided by the contributing drainage area to permit direct comparison between stream gages. As can be expected given the precipitation gradient in the State, MAF also exhibits a strong east-west pattern with much higher normalized streamflows in east Texas than west Texas and the panhandle (Figure 30 and Figure 31).

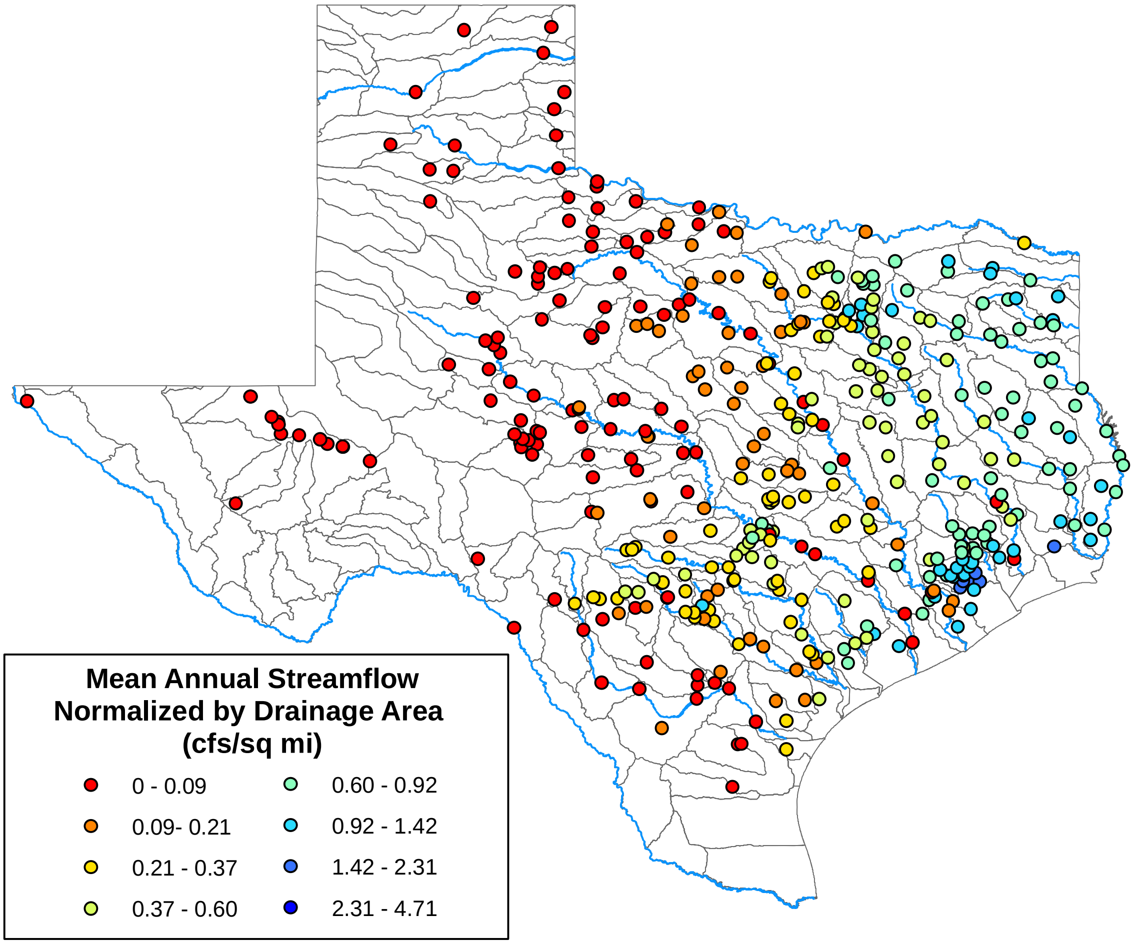

Figure 30. Mean annual streamflow, normalized by contributing drainage area.

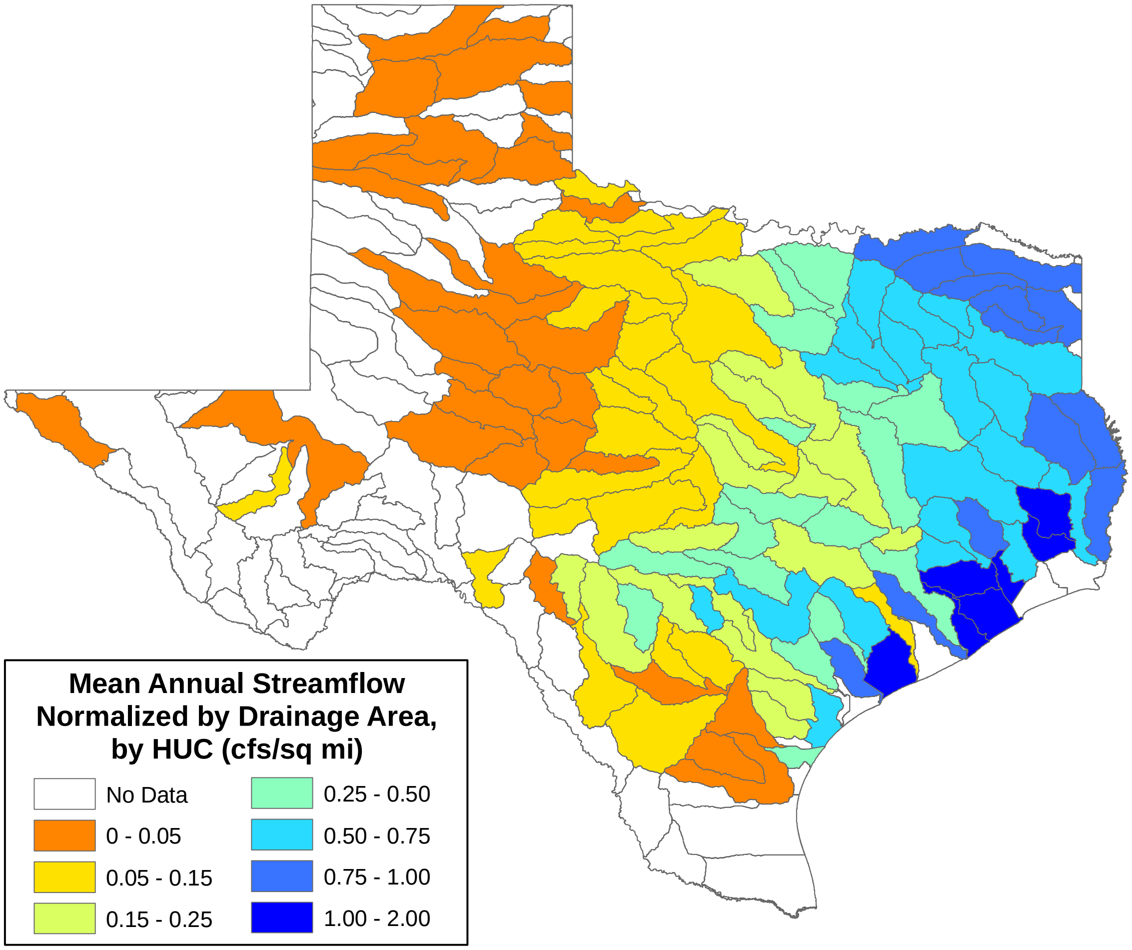

Figure 31. Mean annual streamflow, normalized by contributing drainage area and grouped by HUC.

Mean annual velocity appears to be patterned along the lines of major river basin, with subbasins in the Brazos and Colorado Rivers exhibiting, on average, higher stream velocities than streams in other major basins of the state (Figure 32).

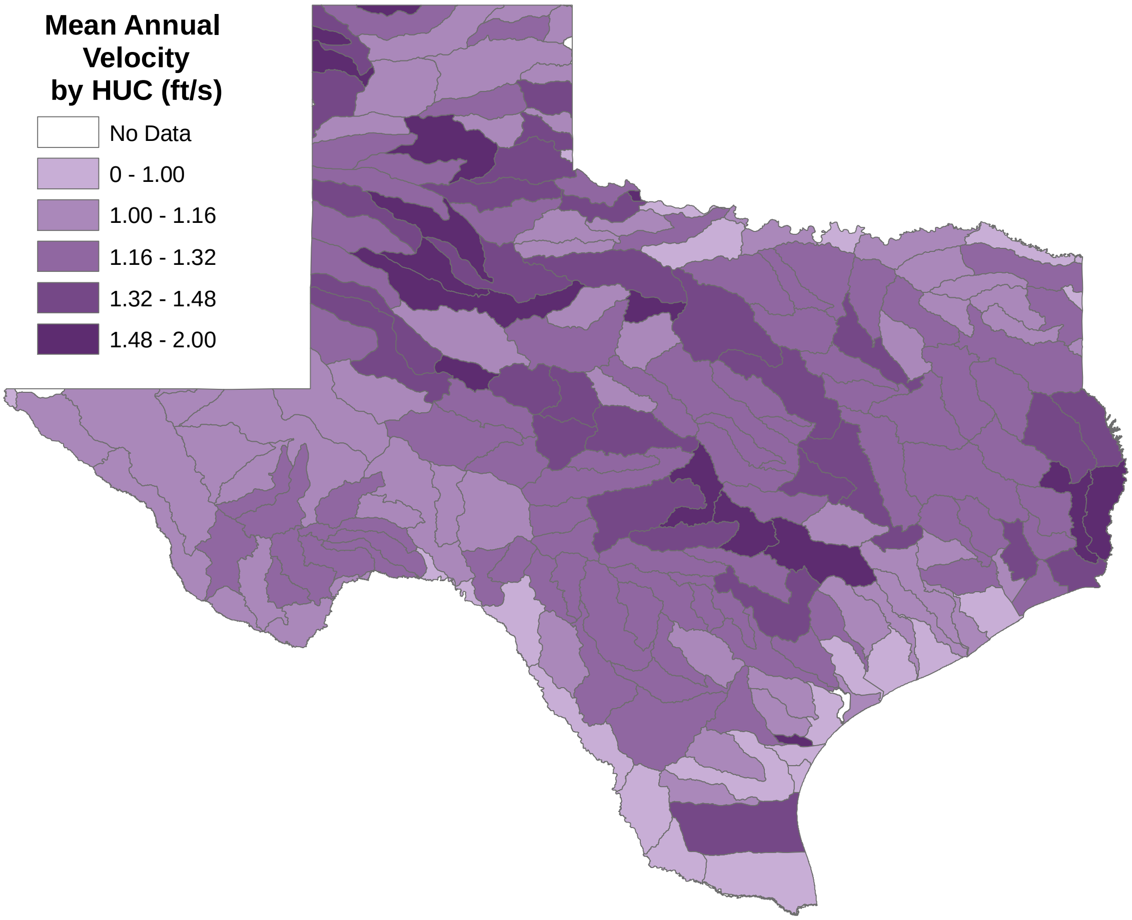

Figure 32. Mean annual stream velocity, by HUC.

In a similar spatial averaging manner as described above, the BFI from the stream gage points within each subbasin was averaged to obtain a mean subbasin BFI (Figure 33 and Figure 34). The presence of isolated springs in the Comal, Frio, and Devils Rivers is strongly evident in the data via higher average base flow indices, as is the artesian zone of the Edwards Aquifer and the generally wetter systems of east Texas (as compared to west Texas).

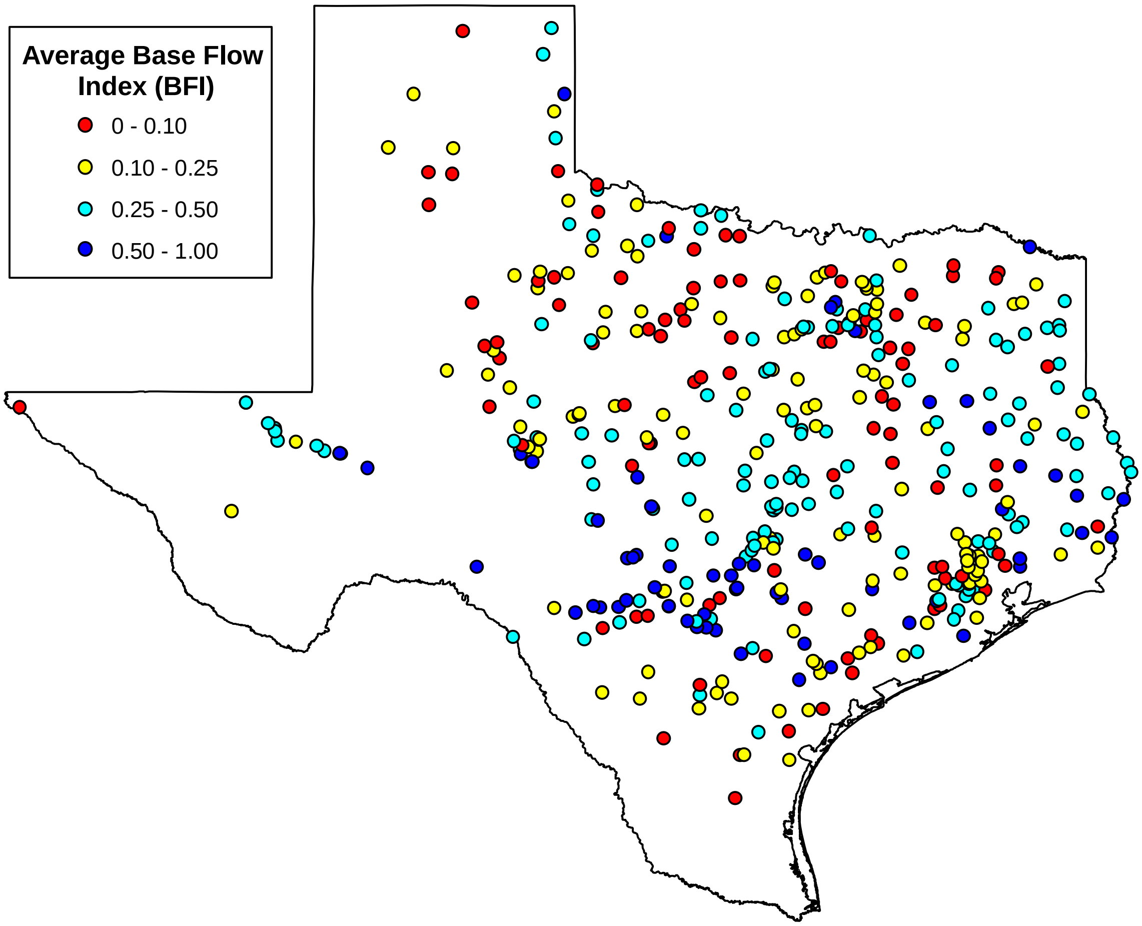

Figure 33. Mean base flow index (BFI) by streamflow gage.

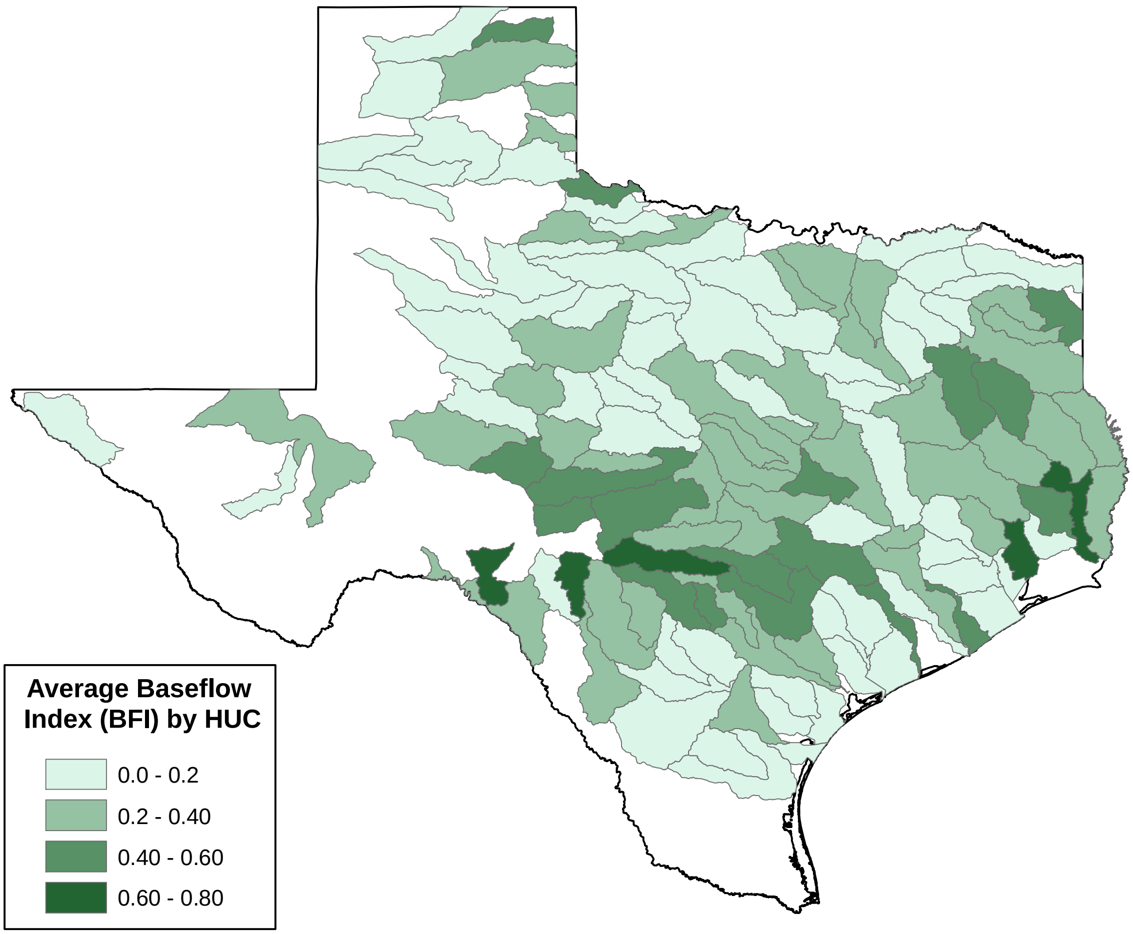

Figure 34. Mean BFI by subbasin.

Just as with the normalized MAF, the percent of zero flow days exhibits an east-west gradient, where very few streams in east Texas are absent of streamflow for any significant number of days (i.e., a greater prevalence of perennial streams), whereas streams in south and west Texas are more likely to experience a majority of days without flow (i.e., a greater prevalence of intermittent streams) (Figure 35 and Figure 36).

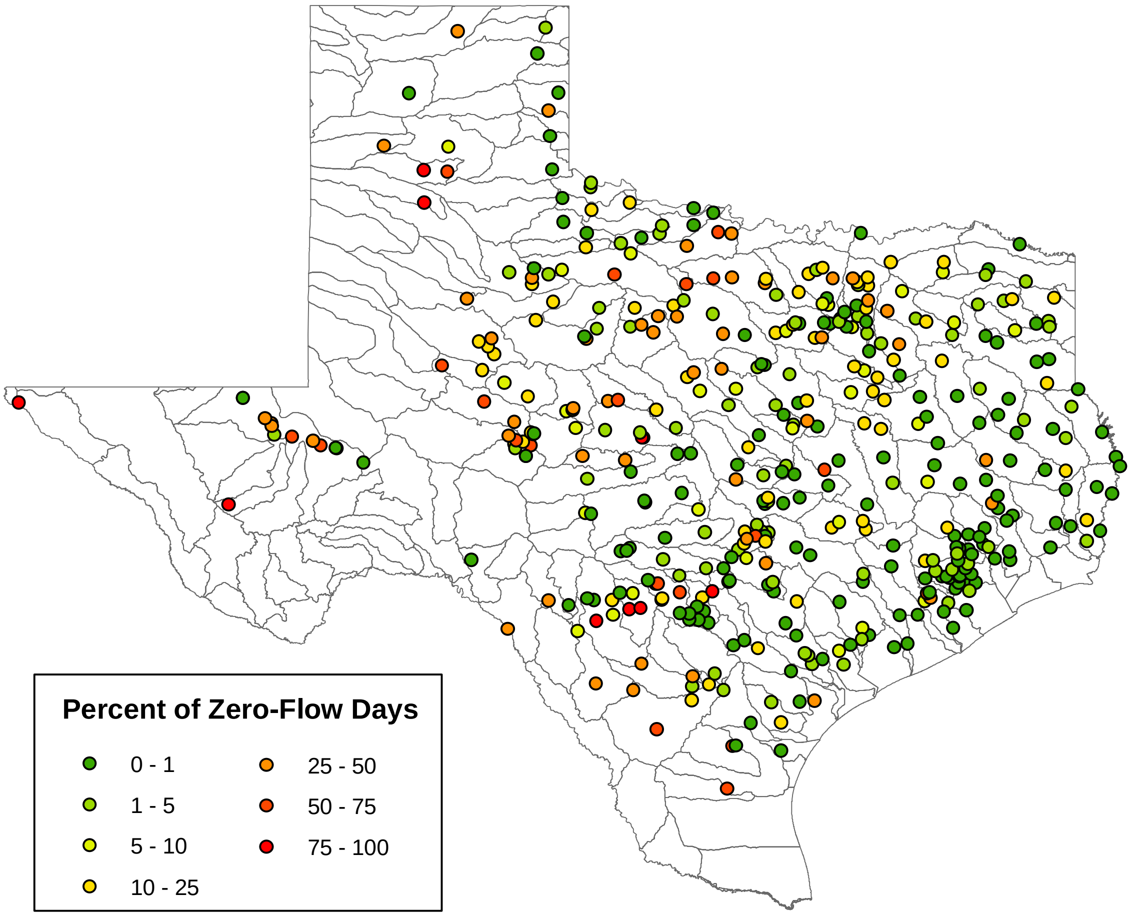

Figure 35. Percent of zero flow days.

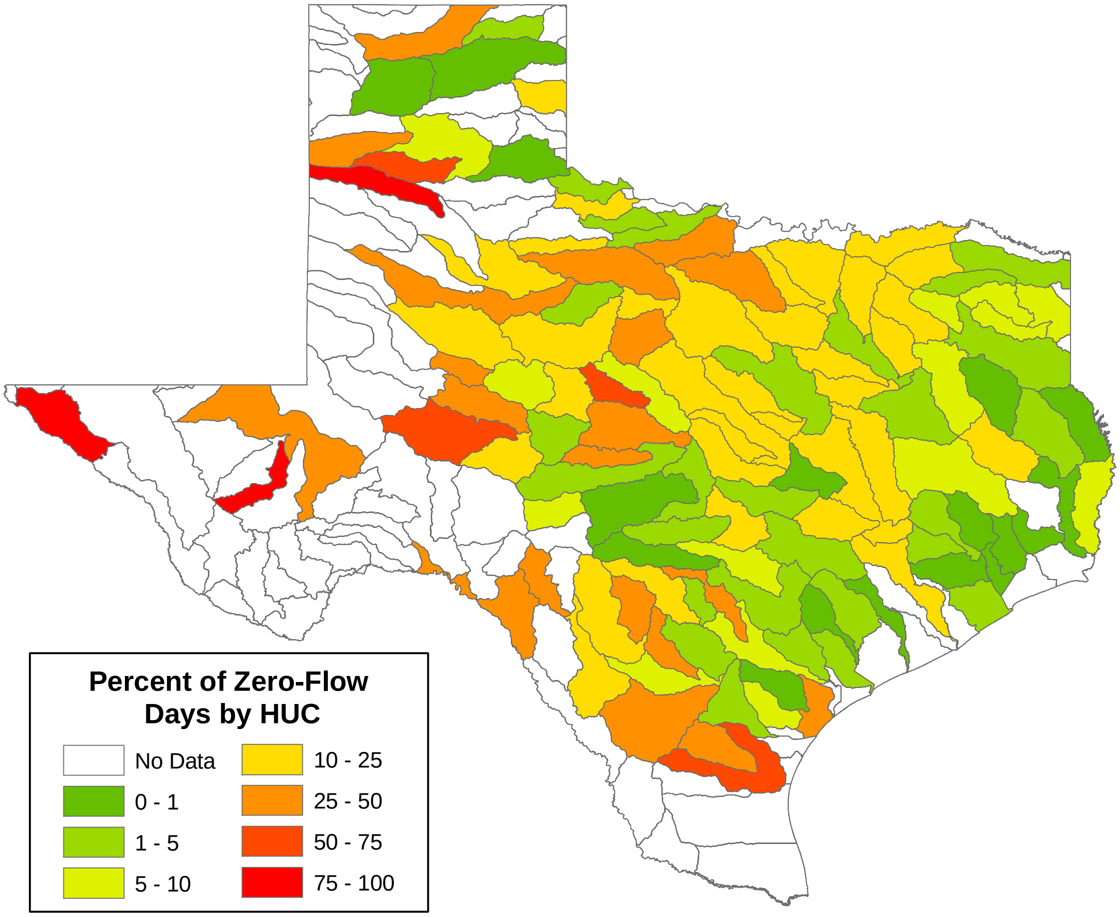

Figure 36. Percent of zero flow days, by HUC.

As with MAF, the IQR was normalized to allow for statewide comparison, in this case by median streamflow. Of the 427 stream gages analyzed having 20 or more years of streamflow data, 33 of the gages had a median streamflow equal to zero (Figure 37), that is, intermittent streams where the majority of days have no streamflow. This subset of 33 gages was excluded from the analysis of flow variability, leaving a sample population of 394 gages. Thus, gages were studied individually and aggregated by subbasin. From this analysis it can be seen that subbasins with a high base flow component and/or occupying a more downstream location in the same river network (i.e., closer to the coast within a river basin that drains to such) exhibit a lesser flow variability (Figure 38 and Figure 39).

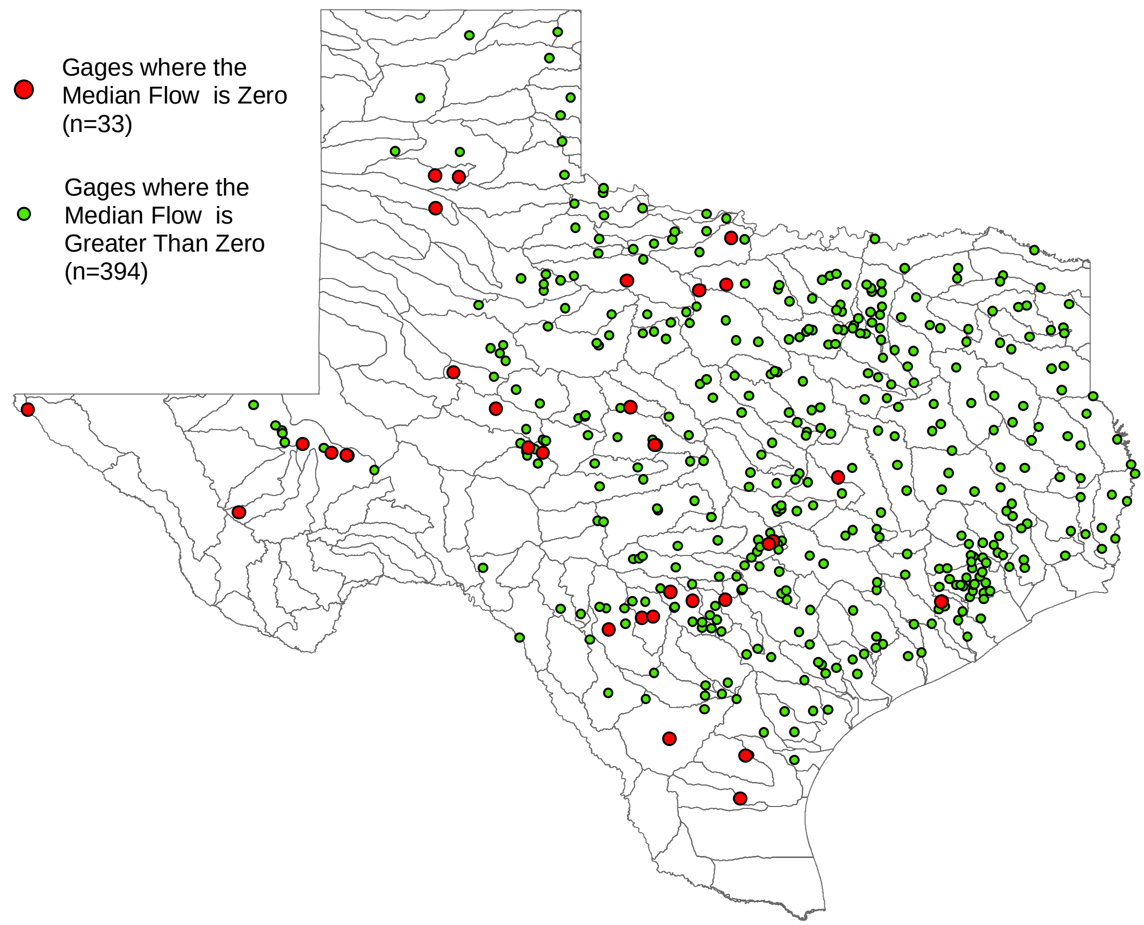

Figure 37. Intermittent streams in Texas (in red), distinguished as having a median streamflow equal to 0 cfs.

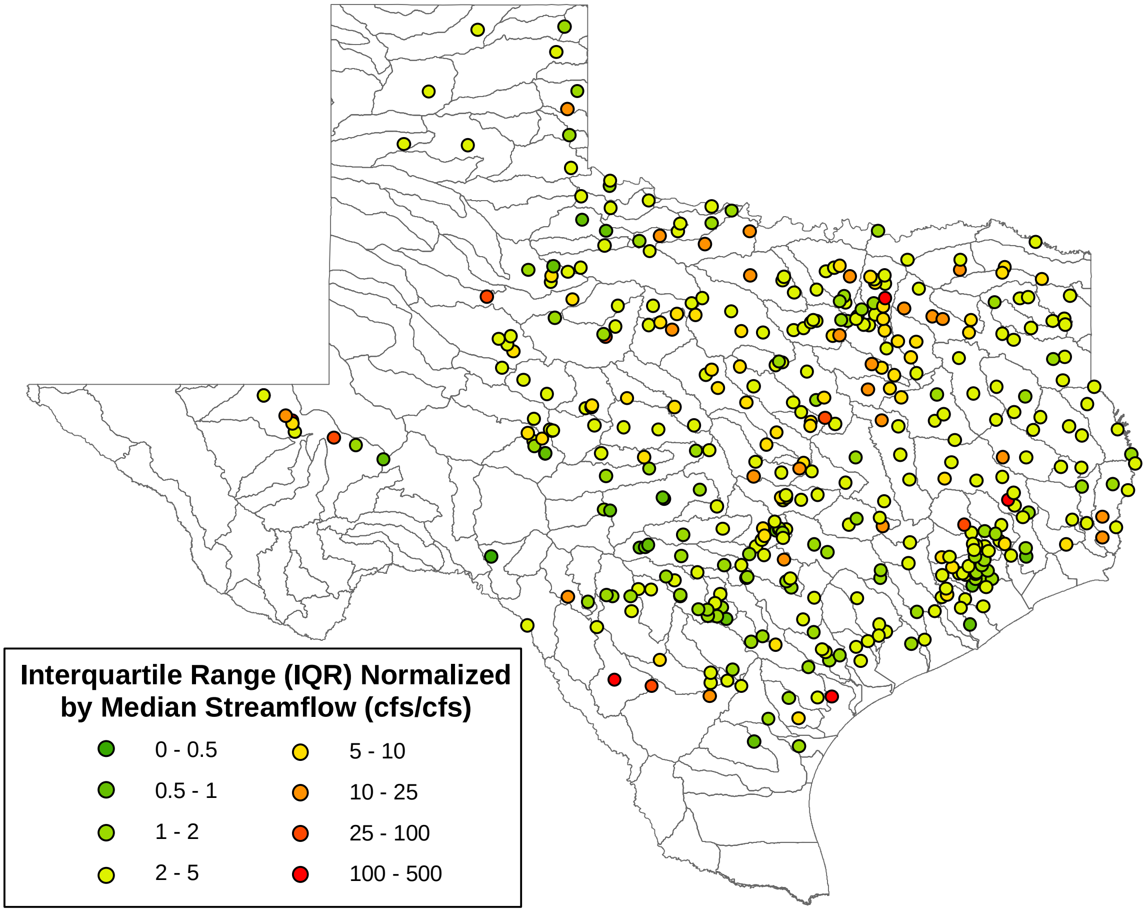

Figure 38. Interquartile range of daily streamflow normalized by median streamflow.

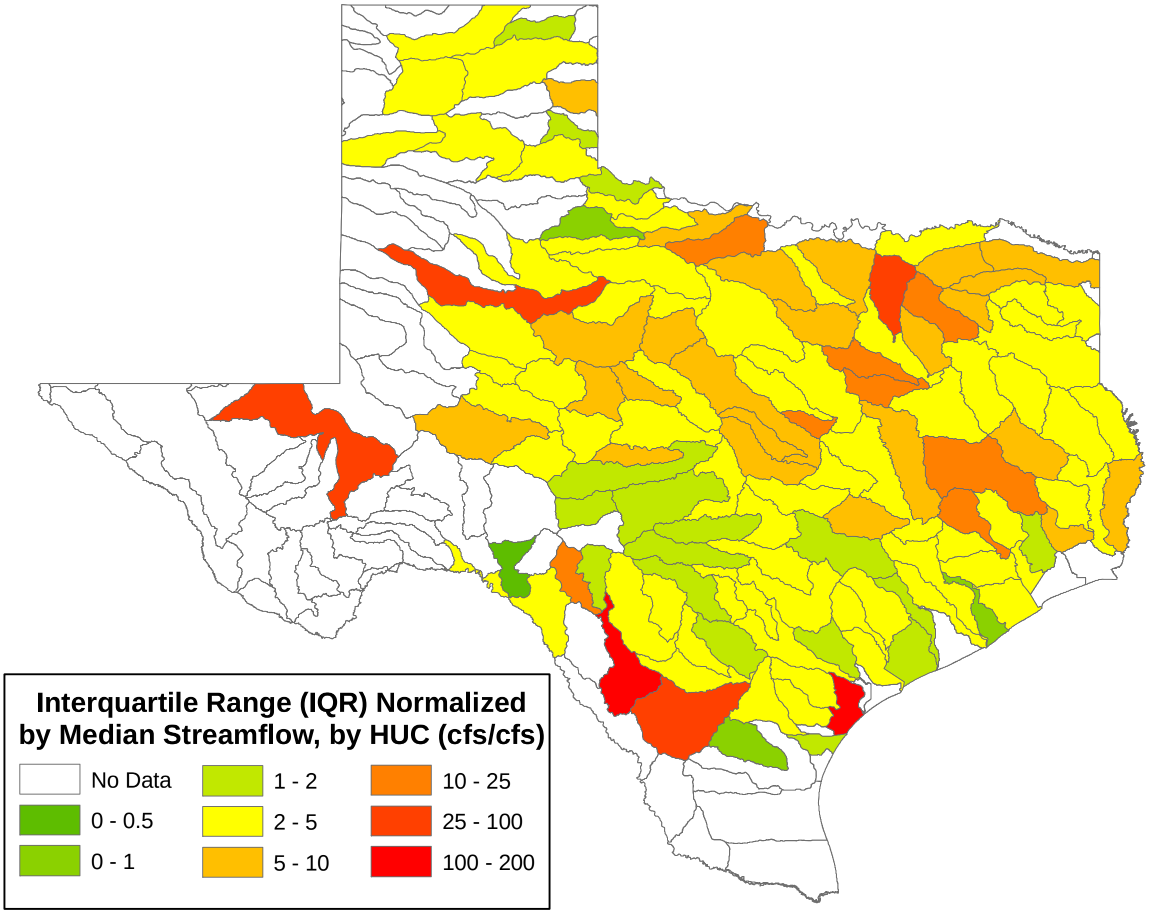

Figure 39. Interquartile range of daily streamflow normalized by median streamflow and grouped by HUC.

4.5 Geomorphology and Physical Processes

4.5.1 Data Sources

"In combination with the hydrologic flow regime, [the physical features of a channel and floodplain] form the habitats to which all biological elements in the river ecosystem have adapted and become dependent" (TIFP 2006). Thus, an understanding of both the physical habitat and the processes and controls that act upon such habitat is of immense importance to developing an understanding of stream ecosystems. In the proposed classification system, the processes of sediment formation, transport, and deposition are respectively represented by consideration of:

- watershed soils composition,
- channel bed slope, and
- stream substrate composition.

Soils and geology are important drivers of water quality, hydrology, geochemistry, substrate composition, channel and floodplain shape and valley confinement (cross-sectional), and planform geomorphology (i.e., sinuosity). They act as a control on the riverine system both at the site of interest through local channel and substrate conditions and through upstream conditions such as infiltration and runoff rates, geochemistry, and sediment load.

Soil composition data have been obtained for Texas from the Conterminous United States Multilayer Soil Characteristics Dataset (CONUS-SOIL) from the Earth System Science Center of Pennsylvania State University (Miller and White 1998). CONUS-SOIL is derived from the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) State Soil Geographic Database (STATSGO). The data include information on soil texture, including: percent clay, percent silt, and percent sand.

Channel bed slope is an important driver of habitat availability as it is a primary factor in determining flow velocity and mesohabitat (pool, riffle, run, etc). Bed slope for each linear stream reach is included in the FlowlineAttributesFlow table in NHDPlus and is calculated by taking the difference in the upstream and downstream node elevations from the National Elevation Dataset divided by the reach length from the National Hydrography Dataset (Figure 40). Also, the marriage of NHD and NED in NHDPlus allows for the examination of the longitudinal stream bed profiles of rivers and streams (Figure 41). These profiles describe the way a stream's elevation (vertical axis) changes over its distance downstream (horizontal axis).

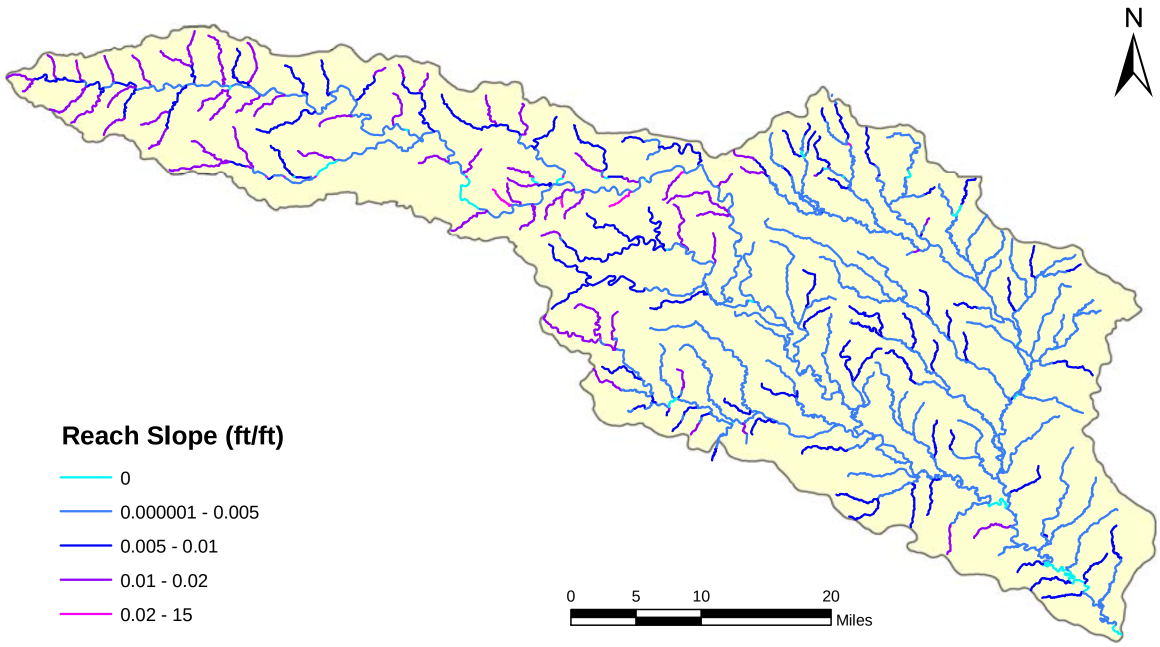

Figure 40. Example NHDPlus map for the San Marcos basin, Texas, depicting channel slope by reach.

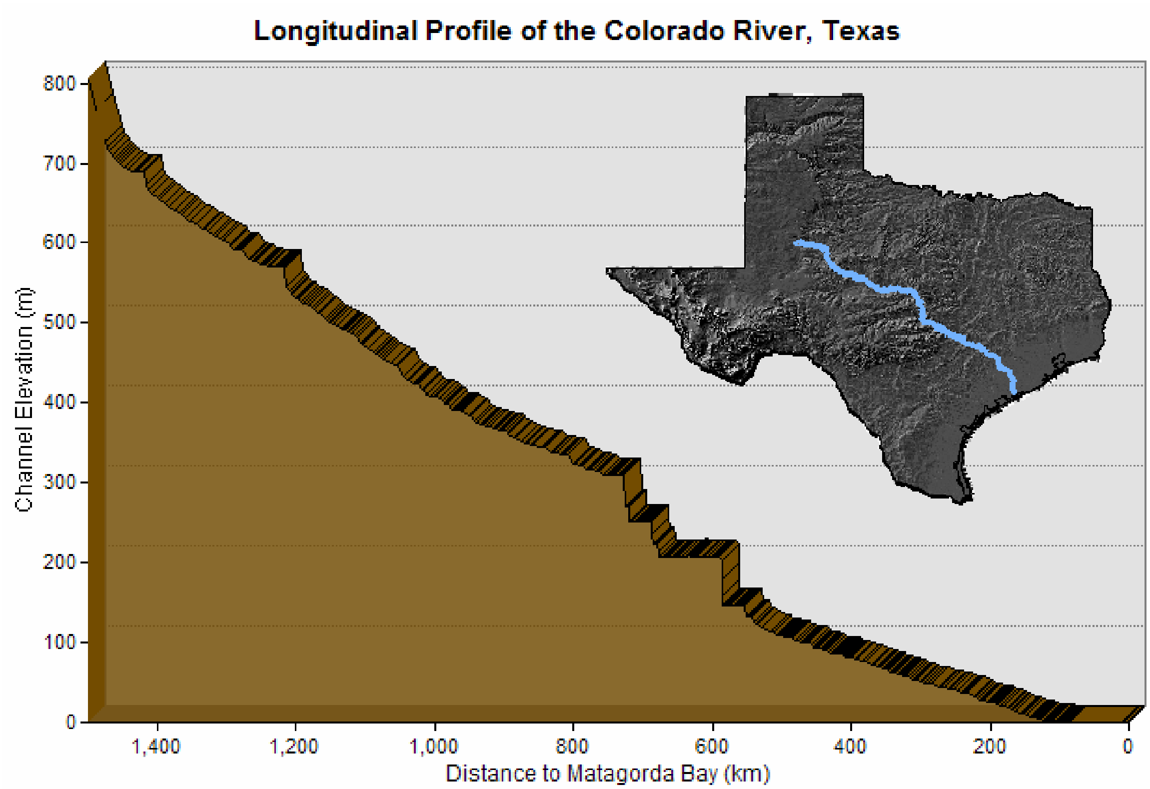

Figure 41. Longitudinal profile of the Colorado River, Texas. Note the step-shaped reaches between kilometers 800 and 550, which are the Highland Lake system reservoirs and dams, with the largest vertical reach (approximately kilometer 590) being Mansfield Dam at Lake Travis.

4.5.2 Geomorphology and Physical Processes Variables

Soil texture of the contributing watersheds of the State, as represented by percent clay, percent silt, and percent sand (Figure 42, Figure 43, and Figure 44), was assessed and averaged by subbasin (Figure 45, Figure 46, and Figure 47, respectively). It can be seen in these figures that the Brazos and Trinity basins, west Texas, and the coastal basins have high clay content, the Devils River basin has high silt content, and the high plains, south Texas, and east Texas regions have high sand content.

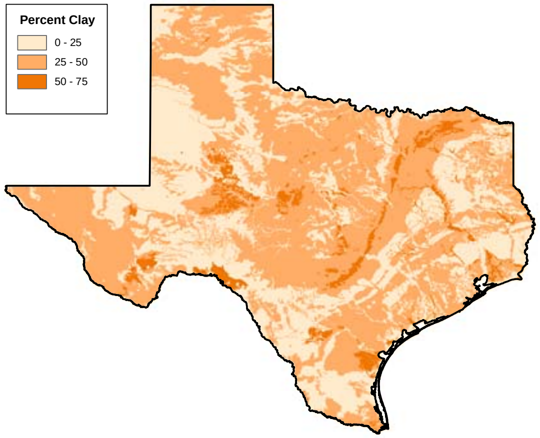

Figure 42. Soil clay composition, in percent.

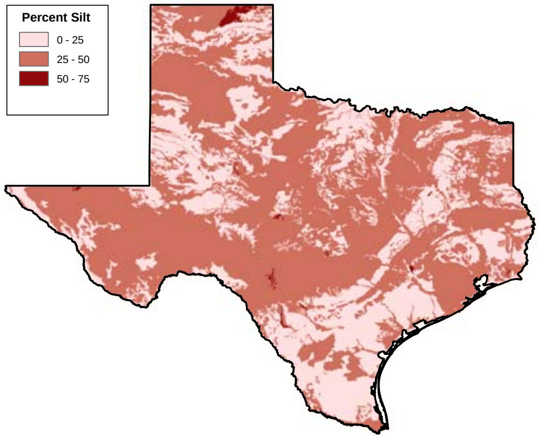

Figure 43. Soil silt composition, in percent.

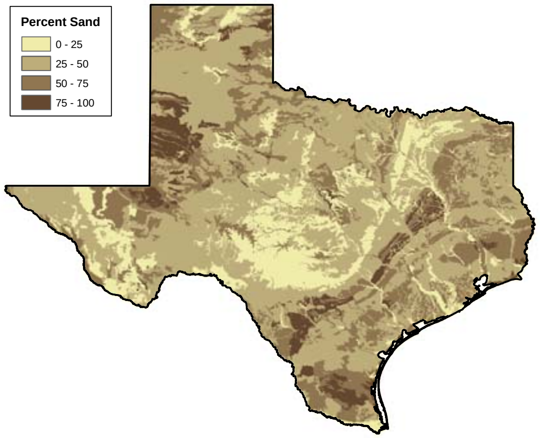

Figure 44. Soil sand composition, in percent.

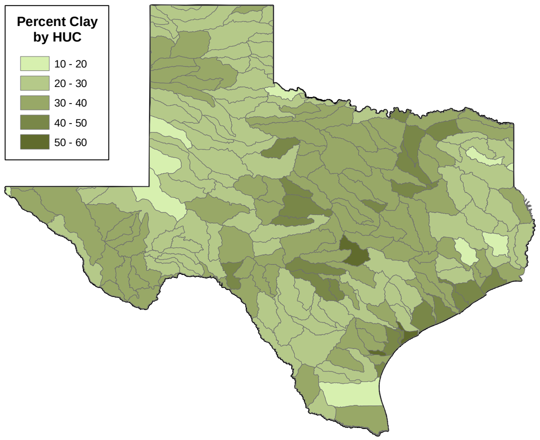

Figure 45. Percent clay by subbasin.

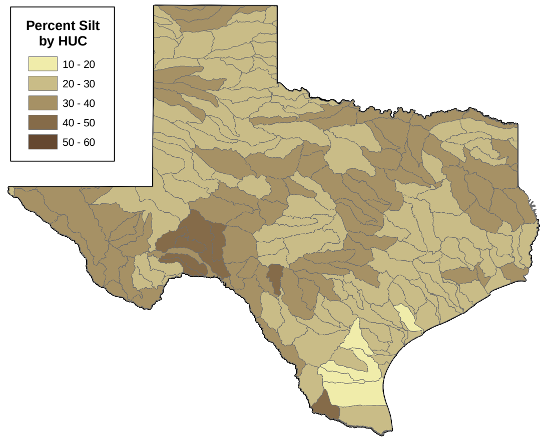

Figure 46. Percent silt by subbasin.

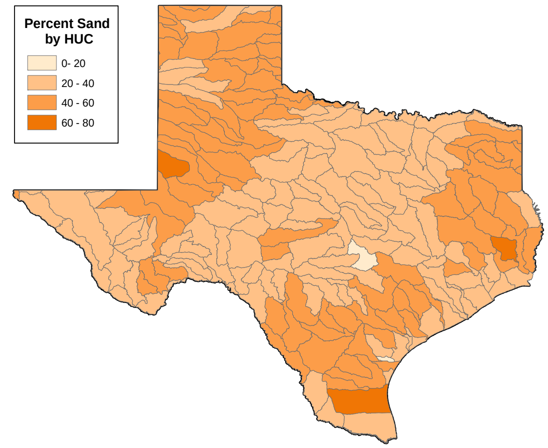

Figure 47. Percent sand by subbasin.

The reach slope within each subbasin was averaged to obtain a mean subbasin bed slope (Figure 48). It is evident that streams are steeper up on the high plains, in west Texas, along the lower Rio Grande, and coming down off the Edwards Plateau than elsewhere in the State.

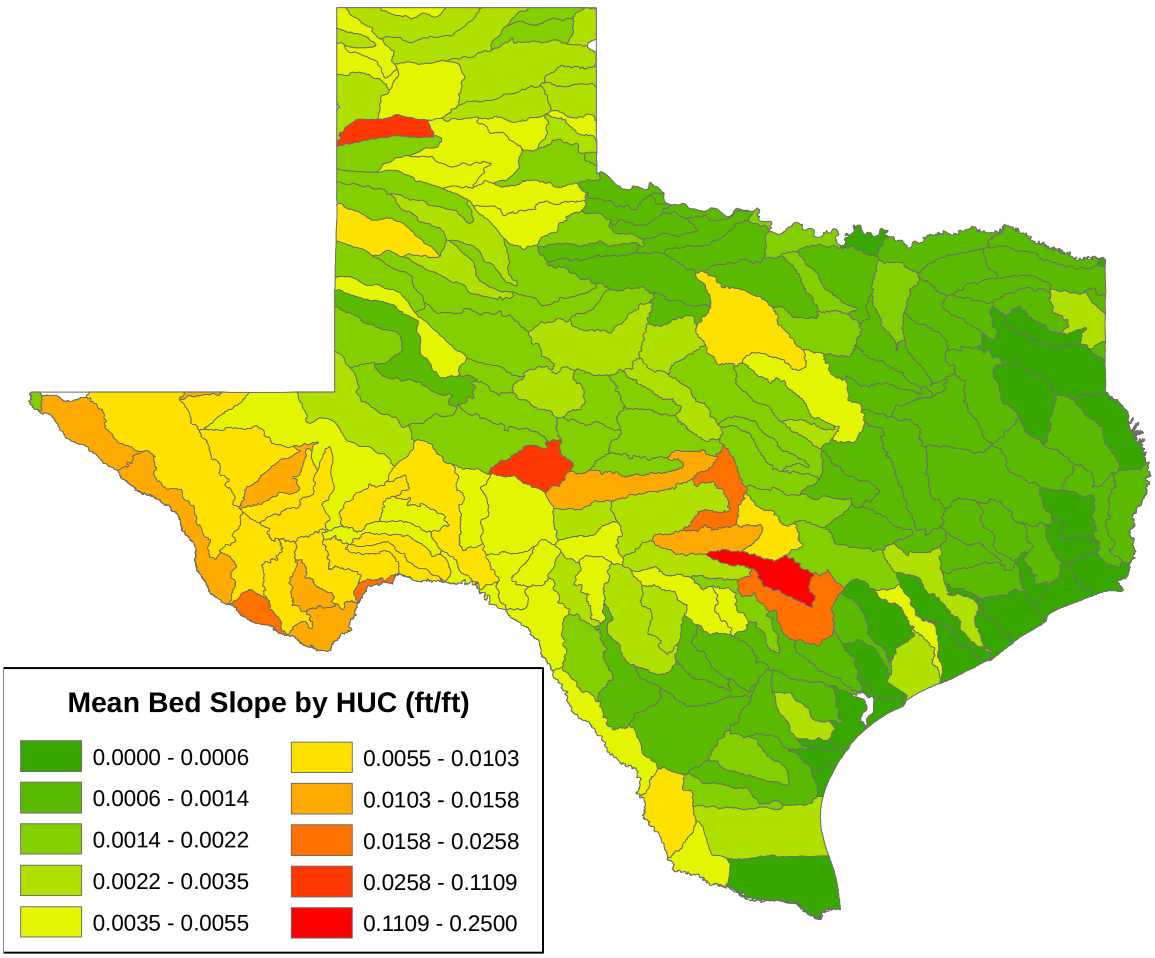

Figure 48. Mean reach bed slope by subbasin.

Channel bed slope was tested for redundancy and correlation with water quality parameters using the same method described for the water quality parameters. As was the case with those parameters, variations in bed slope by subbasin could only explain 1 to 8% of the variation in the water quality parameters (Figure 49). It is possible that stronger linkages between slope and water quality and among water quality parameters may exist on a reach-scale (not tested) than indicated on a subbasin scale (tested). Variation between headwater streams and mainstem rivers and or other physical categories may exist within subbasins, but was not explicitly tested.

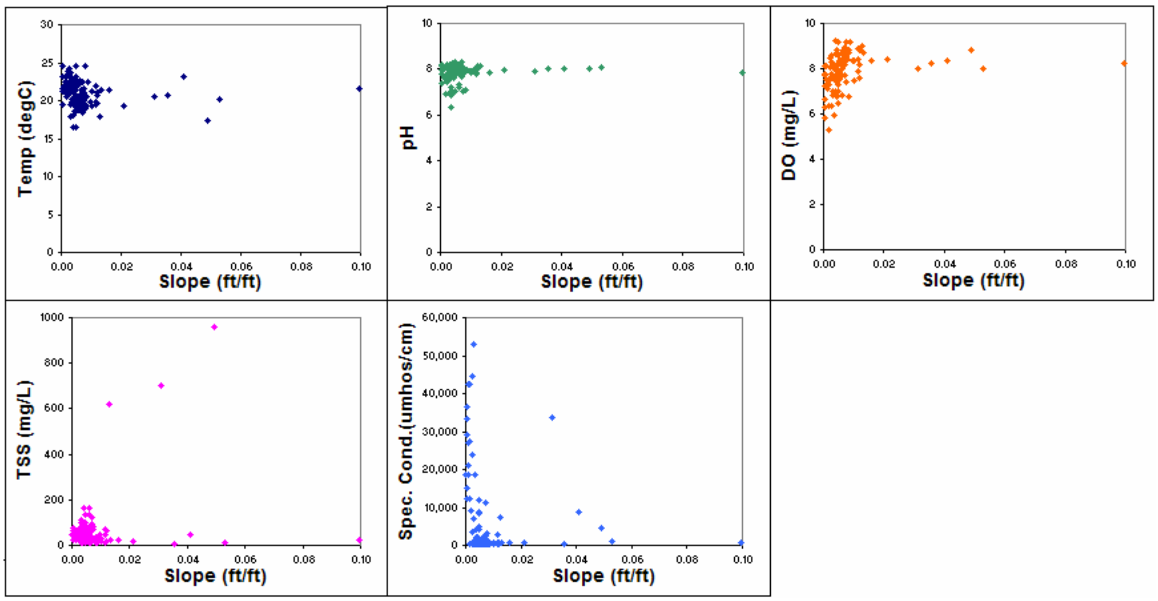

Figure 49. Tests for correlation between each water quality parameter and channel bed slope. Note: scales and correlated variable are not important in this case; plots are simply meant to depict scatter in the data.

The USGS has been compiling and expanding a National Geochemistry Survey to "produce a body of geochemical data for the United States based primarily on stream sediments, analyzed using a consistent set of methods" in order to "enable construction of geochemical maps, refine estimates of baseline concentrations of chemical elements in the sampled media, and provide context for a wide variety of studies in the geological and environmental sciences" (USGS 2004). Accessible at http://tin.er.usgs.gov/geochem/, the database contains records for 2,710 sites in Texas, including 2,379 stream sediment samples (88%) and the remainder being soil samples (Figure 50); only the stream sediment samples were included in the analyses herein.

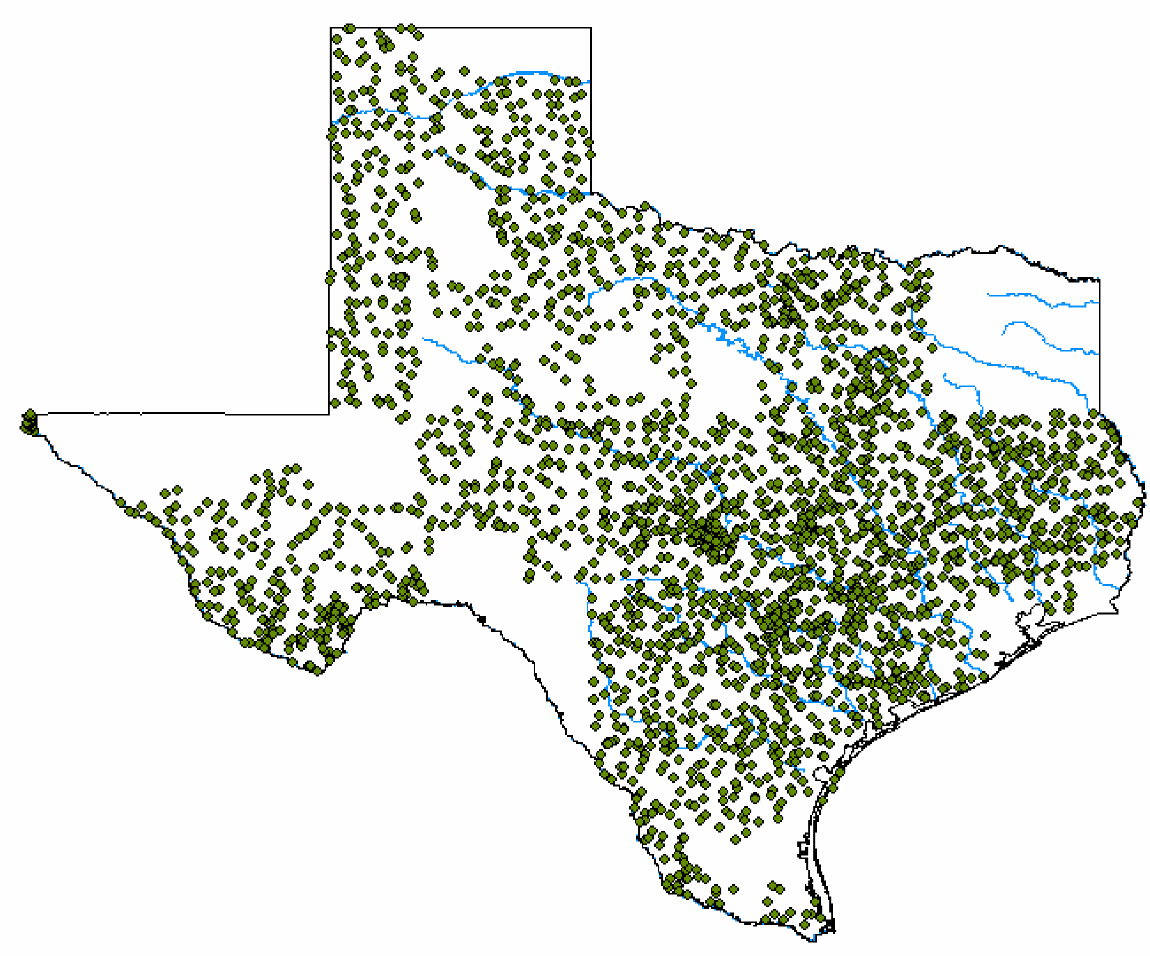

Figure 50. USGS National Geochemistry Survey database sample sites in Texas.

The geochemistry database contains a wealth of information on:

- sample
- geography
- source
- *in situ* sample
- substrate
- channel
- streamflow
- velocity

- possible sample contamination and sources
- water quality
- vegetation
- metals by spectrometry and neutron activation (as percent weight or concentration)
- gasses by atomic absorption
- total and organic carbon
- fertilizers.

TCEQ TRACS also contains information on dominant substrate type (STORET code 89844) from stream samples taken across the State since the 1960s. These data are available at 347 stations with a total of 775 coded records, following the same codes as the National Geochemistry Survey (Table 8).

Table 8. TCEQ TRACS and National Geochemical Survey dominant substrate type code key (STORET 89844).

Dominant Substrate Type	**Code**
Clay	1
Silt	2
Sand	3
Gravel	4
Cobble	5
Boulder	6
Bedrock	7
Other	8

The 1785 stream substrate data records from the National Geochemistry Survey were combined with the corresponding data from TCEQ TRACS for a total of 2560 samples statewide (Figure 51). These data were counted by 8-digit HUC and the most frequently-occurring substrate type within each HUC was reported for each HUC (Figure

52). Although the relative frequency of dominant substrate types within each subbasin is not necessarily an unbiased estimator of the most common substrate types within an area, it is nonetheless a worthwhile means of assessing the relative substrate types and sizes between watersheds. As can be seen, silt and particularly sand are the dominant substrate types in the rivers and streams of Texas, with some regions, particularly the Edwards Plateau and central Texas, having larger dominant substrate types such as gravel, cobble, and even bedrock. When the subbasins are considered in this counted fashion: none had boulders as the dominant substrate type; two had bedrock; and some, particularly along the coast and in the Sulphur and Nueces Basins,, had clay dominating.

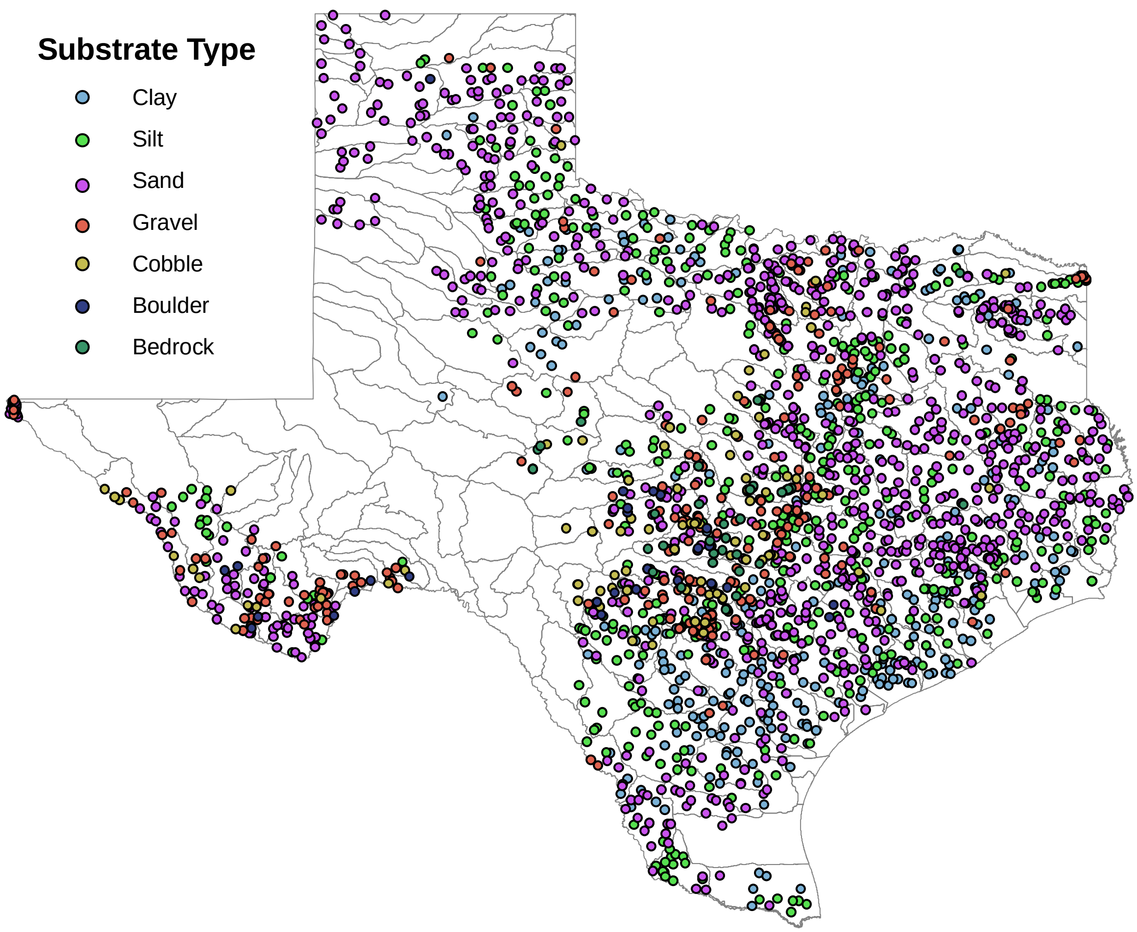

Figure 51. Dominant stream substrate type.

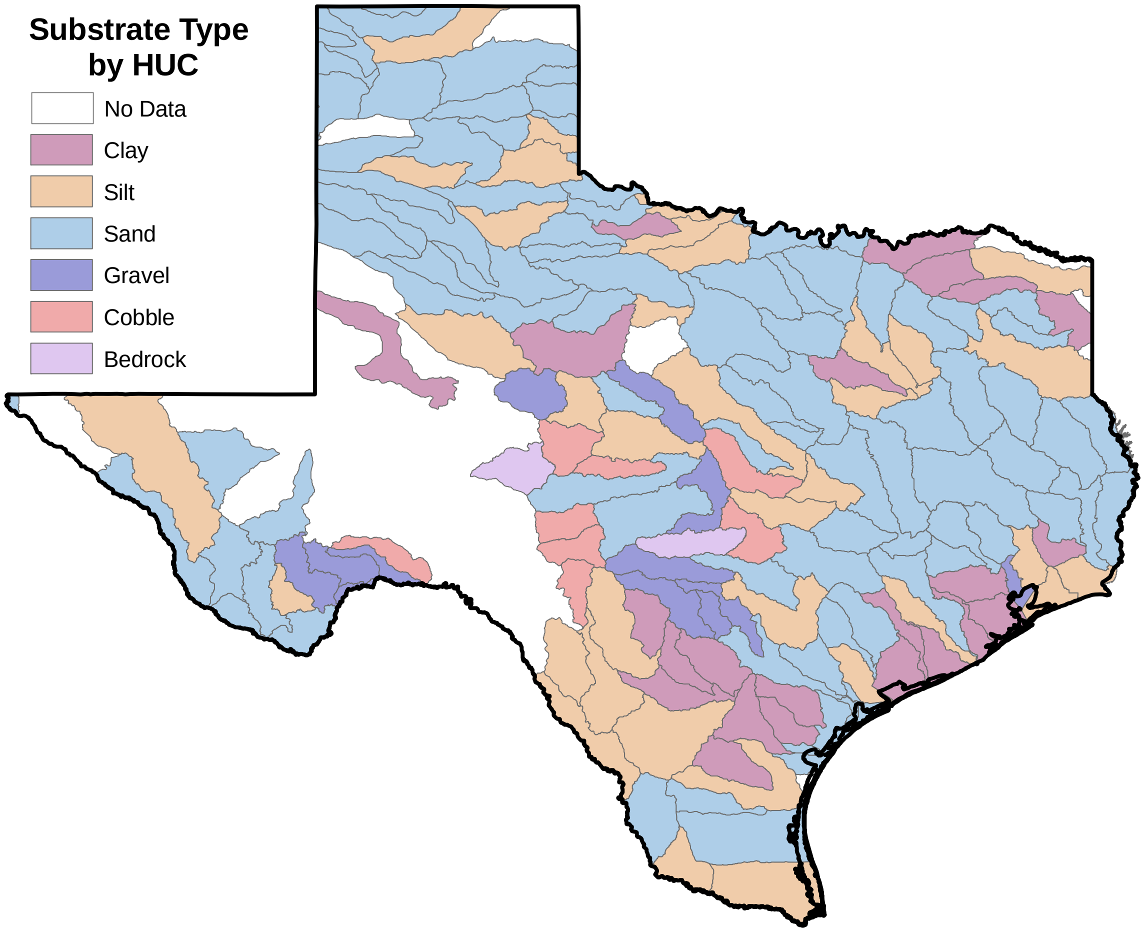

Figure 52. Dominant stream substrate type, by HUC.

4.6 Biology

4.6.1 Data Availability Challenges

Discussions and data exploration exercises conducted as part of the initial phase of this project revealed that biological data are not as well developed or as accessible as other data relevant to stream classification, and the timeframe of various ongoing and future biological data organization endeavors in the State was not conducive for their systematic inclusion in this classification scheme. For these reasons, it was decided that biologic information would not be explicitly incorporated into the initial development phase of the stream classification system. However, the system has been designed to be robust enough to accommodate the future addition of biologic information.

Due in part to the complexity of environmental systems and the sizeable resources required for sample collection, biological data have:

- comparatively limited spatial and temporal coverage,
- greater complexity in the data structure,
- greater flexibility required in the data storage framework, and
- the ability to predict presence of species with confidence, but generally not the ability to predict the absence.

Conceptually, biological data can be viewed as a response variable to the determining factors of physical, chemical, and hydrologic variables. It then follows that driving factors can first be assembled in a predictive classification which can then be subsequently calibrated and validated to the biological data via a multiple-regression style analysis. This is the proposed methodology for future stream classification work.

4.6.2 BIO-AQUATIC INFORMATICS FOR TEXAS WORKGROUP

A biological data workgroup was formed in 2006 with the mission to: discover, deliver, and publish biological data in Texas using a common technology and format. The group has been actively meeting monthly to discuss the issues of biological data discovery, organization, and access. The Bio-Aquatic Informatics for Texas (BAIT) Workgroup has discussed various current and proposed datasets and structures (including USGS, TCEQ, and TPWD scientific collection permit data) and is currently working on a benthics data discovery web portal.

4.6.3 DATA SOURCES

An exploration was made of the coverage and type of biological data within the TRACS SWQM database. Prior to this analysis it was generally believed that the bio-data coverage within SWQM was limited; these quantitative analyses have confirmed this suspicion.

STORET parameter codes within TRACS were divided into groupings of biologic and ecologic significance (Table 9). SQL Queries were then performed in MS Access to extract appropriate data and statistics, and the results of these queries were summarized (Table 10). From these analyses, it was confirmed that TRACS contains relatively little data (number of records) specific to biology, but a large proportion (over 55%) of the codes in TRACS are dedicated to biologic data.

Table 9. Groupings of STORET parameters developed for analysis of the TRACS SWQM database.

Category	Description
Site and Sample	Including: sampling effort, methods, and equipment; substrate, channel geometry, geomorphology, streamflow, cover, vegetation, watershed, aesthetics, and weather
Benthic Macroinvertebrates	Animals without backbones which live all or part of their lifecycle in or near the bottom of freshwater systems. Including: Platyhelminthes (flatworms), Annelids (worms, leeches), Arthropods (mites, insects, crustaceans), and Mollusks (clams, mussels, snails)
Fish	Vertebrate cold-blooded animals that live their entire lives in water, breathe by means of gills, and move by means of fins (with some exceptions)
Phytoplankton	Microscopic, free-floating or suspended plants and algae which have movement depending on currents and are primary producers
Zooplankton	Microscopic animals capable of movement and are secondary producers. Including: crustaceans and rotifers, diatoms, dinoflagellates, and copepods.
Nekton (non-fish)	Free swimming organisms, exclusive of fish as defined above. Including: Decapods (shrimp, prawns, crayfish, crabs), jellyfish, squid, turtles, frogs, alligators
Macrophytes	Large vascular aquatic plants, growing in or near water that are either emergent, submergent, or floating. Including: cattails, rushes, arrowhead, waterlily

Table 10. Summary of biologic data in TRACS SWQM.

Category	Records		Code	
	Count	% of TRACS	Count	% of TRACS
TRACS SWQM	7,591,675	100.00%	4,412	100.0%
Site and Sample	184,935	2.44%	82	1.9%
Benthic Macroinvertebrates	49,402	0.65%	1,323	30.0%
Fish	32,710	0.43%	311	7.0%
Phytoplankton	10,099	0.13%	371	8.4%
Zooplankton	10,344	0.14%	266	6.0%
Nekton (non-fish)	2,942	0.04%	31	0.7%
Macrophytes	449	0.01%	54	1.2%
Total, Biologic Data in TRACS	**290,881**	**3.83%**	**2,438**	**55.3%**

Additional biological/ecological data sources actively being explored and considered for possible future inclusion:

- A sizeable (on the order of 16,000 unique records from 31 museum collections worldwide) georeferenced database of fishes of Texas from the Texas Natural Science Center Texas Natural History Ichthyology Collection
- Fishes and habitat dataset from Professor Timothy Bonner of Texas State University from sampling and analyses conducted on the Blanco River
- USGS National Water Quality Assessment (NAWQA) Program data for fishes and benthics.

5. A STREAM CLASSIFICATION SYSTEM FOR TEXAS

5.1 Data Integration

5.1.1 GENERALIZED DISTRICTS

A meeting of stakeholders and users of the integrated stream classification system was held on April 6, 2007 to share ideas and solicit feedback and suggestions; attendees included researchers, state agency officials, and environmental organization representatives. One goal was to evaluate the generalized districts presented in the NRC report and make consensus-based modifications based on a collective wealth of experience with the issues, conditions, and waterways of the State. The stakeholder panel was largely in agreement with the districts as originally presented, with the one exception being that the conditions typical of the Devils River basin and its tributaries are more commonly observed in South-Central Texas streams than West Texas streams. Thus, four subbasins were switched from the Lower Rio Grande Basin district to the South Central Texas district (Table 11 and Figure 53) and the generalized districts were revised accordingly to reflect the consensus-based regionalization (Figure 54).

Table 11. Devils River subbasins switched from the Lower Rio Grande Basin to the South Central Texas Basin based on stakeholder consensus.

HUC	Name
13040301	Upper Devils
13040302	Lower Devils
13040303	Dry Devils
13070011	Howard Draw

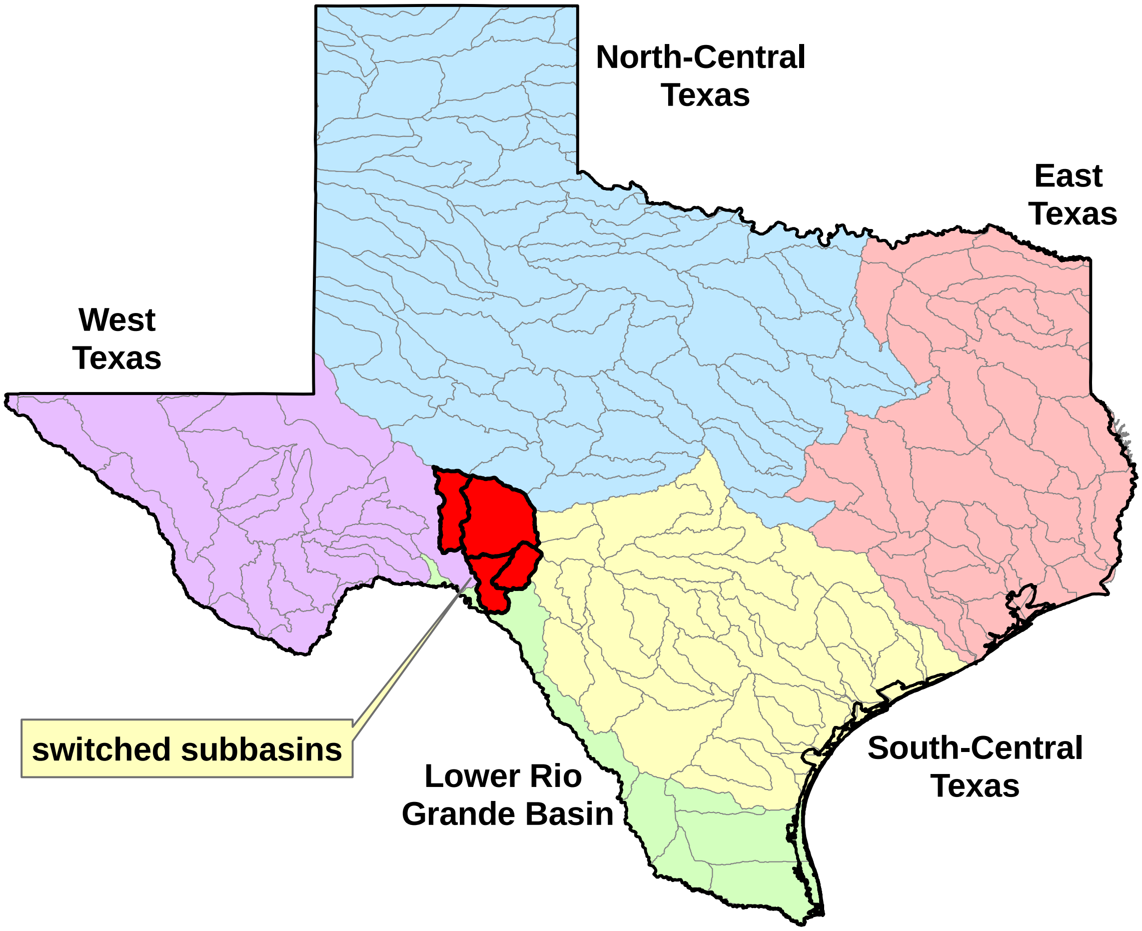

Figure 53. Devils River subbasins switched from the Lower Rio Grande Basin to the South Central Texas Basin based on stakeholder consensus.

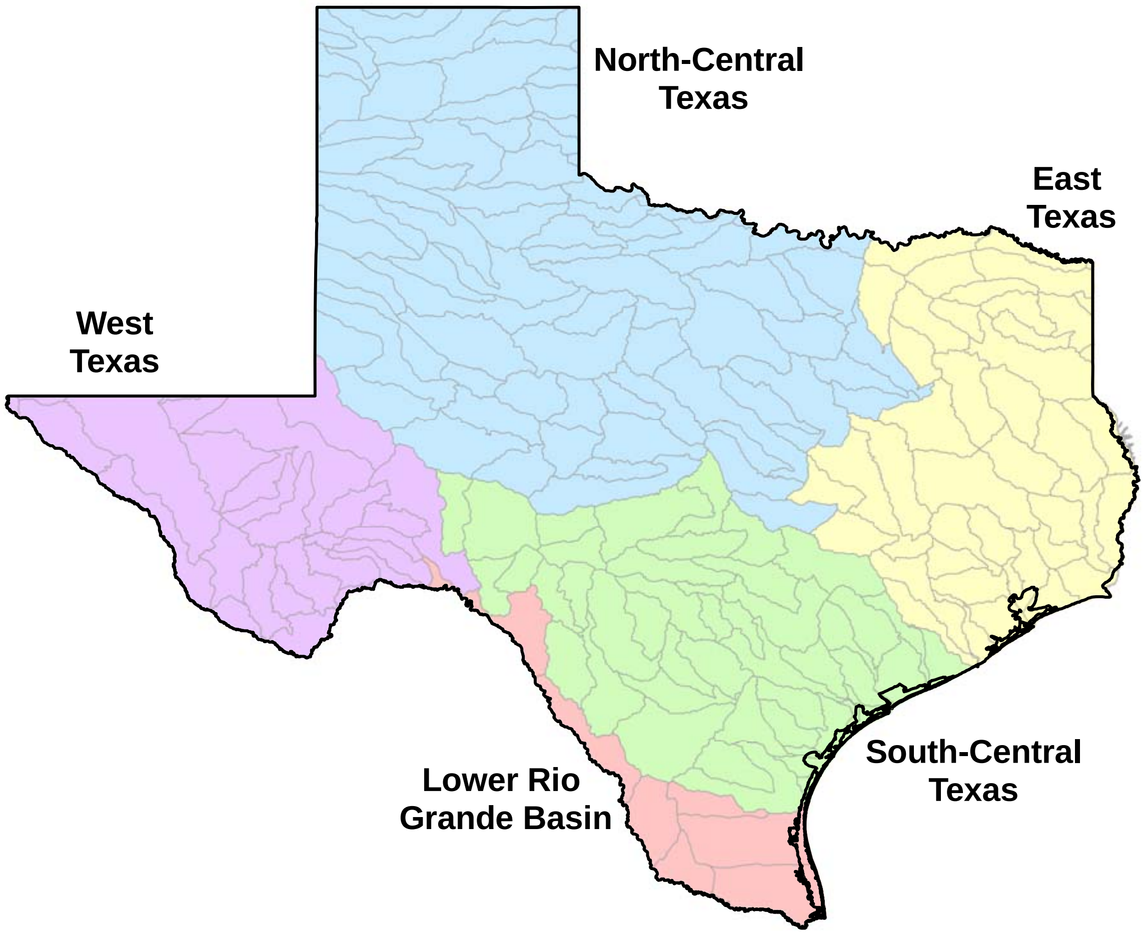

Figure 54. Stakeholder consensus-based revision of generalized NRC districts.

These five districts were used as the baseline case for data integration and evaluation and served as the point for departure in the development of the integrated stream classification system for Texas.

5.1.2 Distinguishing Parameters

Eighteen distinguishing parameters from four disciplines were incorporated into the stream classification system (Table 12).

Table 12. Distinguishing parameters of the riverine environment incorporated into the stream classification system and their units.

Theme	Variable	Units
Water Quality	Dissolved Oxygen	mg/L
	Stream Temperature	°C
	Total Suspended Solids	mg/L
	pH	pH units
	Specific Conductance	μS/cm
Climatology	Mean Annual Air Temperature	°C
	Mean Annual Precipitation	in
	Mean Annual Potential Evapotranspiration	in
Hydrology & Hydraulics	Mean Annual Normalized Streamflow	cfs/cfs
	Mean Annual Velocity	fps
	Base Flow Index	-
	Percent of Zero Flow Days	%
	Normalized Interquartile Range	cfs/cfs
Geomorphology & Physical Processes	Bed Slope	ft/ft
	Dominant Substrate Type	Coded, 1-7
	Watershed Soils Sand Fraction	-
	Watershed Soils Silt Fraction	-
	Watershed Soils Clay Fraction	-

5.1.3 REDUNDANT SUBBASINS

Of the 211 subbasins (8-digit HUCs) contained in Texas, 199 are unique and contiguous, meaning that those straddling the state boundary are diminished in size from their original representation in NHDPlus, but the entire contributing area is contained within one cohesive polygon. Additionally, six subbasins at the state boundary have been divided such that two different polygons with the same hydrologic unit code are included within the total count of 211 (Figure 55 and Table 13). Thus, there are a total of 205 unique HUCs in Texas but 211 total subbasins.

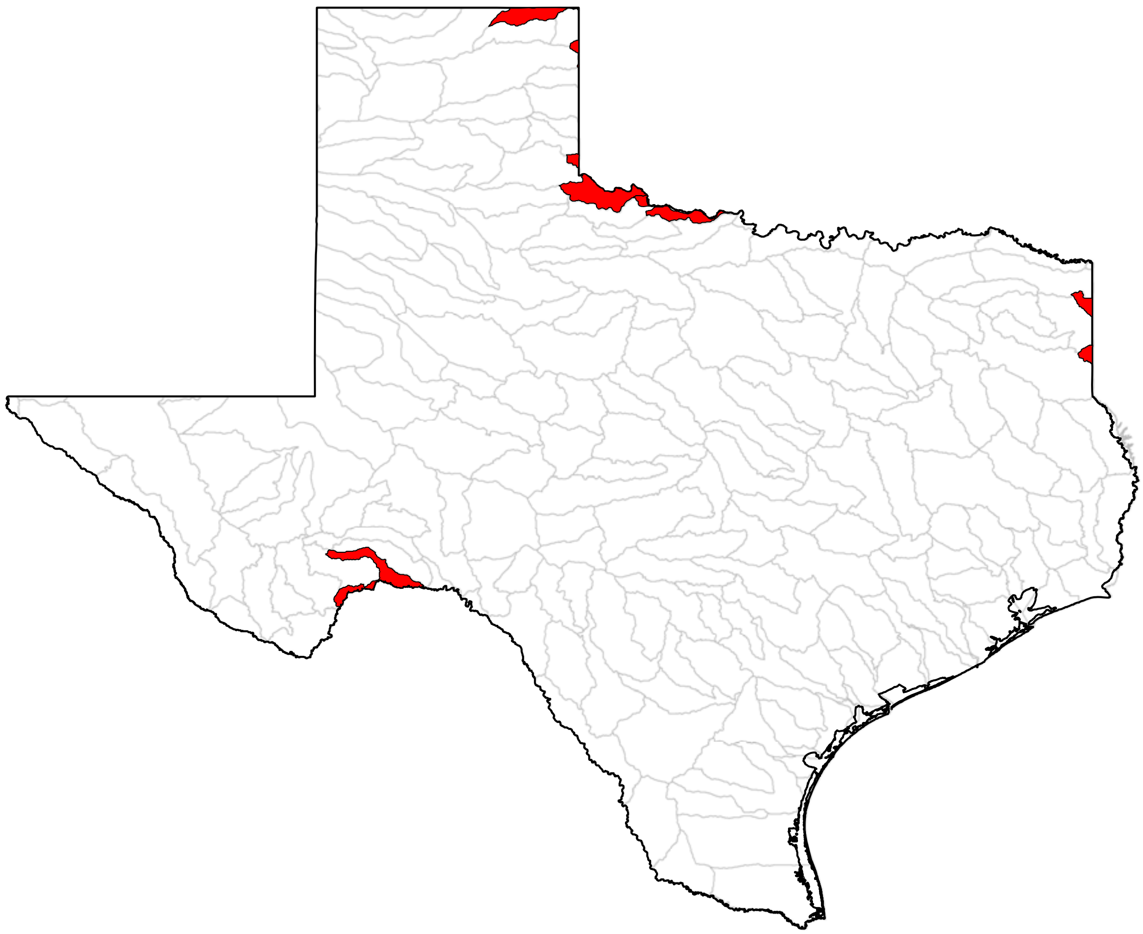

Figure 55. The six subbasins at the state boundary and have been divided into multiple polygons.

Table 13. Attributes of the six subbasins which lie at the state boundary and have been divided into multiple polygons.

Attributes of Redundant_HUCs2

FID	Shape *	HUC	NAME	Area_SQKM	NRC_REGION
0	Polygon	11100201	Lower Beaver	1111.88485	North_Central_Texas
1	Polygon	11100201	Lower Beaver	10.053846	North_Central_Texas
2	Polygon	11090201	Lower Canadian-Deer	120.763509	North_Central_Texas
3	Polygon	11090201	Lower Canadian-Deer	7.276496	North_Central_Texas
4	Polygon	11130101	Groesbeck-Sandy	164.935254	North_Central_Texas
5	Polygon	11130101	Groesbeck-Sandy	1889.341784	North_Central_Texas
6	Polygon	11130102	Blue-China	151.593854	North_Central_Texas
7	Polygon	11130102	Blue-China	799.262551	North_Central_Texas
8	Polygon	11140304	Cross Bayou	351.778783	East_Texas
9	Polygon	11140304	Cross Bayou	245.052926	East_Texas
10	Polygon	13040208	Reagan-Sanderson	1406.497368	West_Texas
11	Polygon	13040208	Reagan-Sanderson	449.78662	West_Texas

Record: 0 Show: All Selected Records (0 out of 12 Selected)

5.2 Analysis of Original Generalized Districts

An analysis was made of the eighteen distinguishing parameters based on grouping by the original NRC Generalized Districts from the "Physical Settings for Instream Flows" description (NRC 2005) (Table 14, Table 20, and Appendix B – Supporting Data). In addition, the qualitative distinctions highlighted in the NRC Report were tested with the results of the quantitative analysis based on the data types examined here for: East Texas (Table 15), North Central Texas (Table 16), South Central Texas (Table 17), the Lower Rio Grande Basin (Table 18), and West Texas (Table 19).

Table 14. Count and area of subbasins grouped by the original generalized districts in Texas.

Class	Count	Total Area (sq km)
North_Central_Texas	86	277,010
East_Texas	43	136,324
South_Central_Texas	46	145,581
Lower_Rio_Grande_Basin	9	36,541
West_Texas	27	97,215
Total	**211**	**692,671**

Table 15. Comparison of qualitative distinctions and quantitative data for East Texas.

NRC Qualitative Distinction	Quantitative Result	Assessment
30-50 inches average precipitation	36-56 inches average precipitation	Accurate
Flat landscapes	Lowest average stream slope (0.0008 ft/ft)	Accurate
Clay-rich or sandy soils	Median percentage of clay and sand content of all regions; more clay and sand that silt	Inconclusive distinction
High flow variations	Median normalized IQR	Inconclusive distinction
High turbidity	Lowest TSS (and specific conductance) of all regions	Not supported by the TSS data, although turbidity is not necessarily directly related to TSS
Soft, shifting substrate	Smallest substrate class (silt) of any region	Accurate

Table 16. Comparison of qualitative distinctions and quantitative data for North Central Texas.

NRC Qualitative Distinction	**Quantitative Result**	**Assessment**
15-28 inches average precipitation	15-39 inches average precipitation	Generally accurate
Clay-rich soils	Second-highest clay content of all regions	Accurate
Flood pulses & high flow variations (drought/flood)	Second-lowest IQR of all regions	Inaccurate on a daily time step; inconclusive over longer timeframes

Table 17. Comparison of qualitative distinctions and quantitative data for South Central Texas.

NRC Qualitative Distinction	**Quantitative Result**	**Assessment**
10-40 inches average precipitation	18-46 inches average precipitation	Accurate
Clear water	Second-lowest TSS of all regions	Accurate
Cool water	Second-warmest water temperature of all regions	Not supported by the data
High base flow index	Highest BFI of all regions	Accurate

Table 18. Comparison of qualitative distinctions and quantitative data for Lower Rio Grande Basin.

NRC Qualitative Distinction	Quantitative Result	Assessment
11-26 inches average precipitation	20-27 inches average precipitation	Generally accurate
Rio Grande occasionally reduced to series of isolated pools	Lowest mean stream velocity, second-highest percentage of zero flow days of all regions	Inconclusive based on available data
Rio Grande occasionally fails to reach Gulf of Mexico	Second-highest percentage of zero flow days of all regions	Inconclusive based on available data, but observed
Stressed aquatic biota	Highest water temperature, highest pH, highest specific conductance, highest air temperature, lowest stream velocity, second-highest percentage of zero flow days, lowest IQR of all regions	Inconclusive but probable based on available data

Table 19. Comparison of qualitative distinctions and quantitative data for West Texas.

NRC Qualitative Distinction	Quantitative Result	Assessment
8-16 inches average precipitation	11-19 inches average precipitation	Accurate
High salinity in Pecos	Median specific conductance of all regions (for entire West Texas region) but high in Pecos reaches	Accurate

Table 20. Mean, standard deviation, and coefficient of variation statistics for the original generalized districts of Texas; blank cells indicate insufficient data.

Mean - Original Generalized Districts

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay
East_Texas	7.30	20.54	42.56	7.36	3308	18.26	46.00	54.73	0.77	1.20	0.27	6.03	5.77	0.0008	2.41	31.77	22.92	23.89
Lower_Rio_Grande_Basin	7.94	23.04	64.05	8.05	14587	21.66	23.83	56.28		0.99	0.28	29.55	4.00	0.0041	2.50	36.91	21.74	22.57
North_Central_Texas	8.55	18.88	126.80	8.02	3687	15.71	24.14	59.78	0.12	1.27	0.20	18.81	5.20	0.0046	2.82	33.06	23.00	24.22
South_Central_Texas	7.88	21.95	49.78	7.95	10349	19.75	30.62	58.17	0.27	1.19	0.30	14.84	12.68	0.0089	2.70	28.46	19.87	24.66
West_Texas	8.38	19.28	341.00	8.02	3923	16.49	15.41	66.17	0.02	1.12	0.18	72.06	41.35	0.0097	3.21	24.23	22.91	20.50

Standard Deviation - Original Generalized Districts

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay
East_Texas	0.92	1.55	35.76	0.45	5935	1.09	4.49	0.69	0.299	0.17	0.16	5.46	6.09	0.00055	0.85	8.96	3.83	5.57
Lower_Rio_Grande_Basin	0.59	1.41	16.21	0.14	20624	0.86	2.82	2.21		0.19				0.00295	0.59	21.03	4.77	5.39
North_Central_Texas	0.77	1.66	230.99	0.20	6874	1.88	6.11	2.62	0.151	0.19	0.12	18.26	4.15	0.01405	0.95	10.35	3.52	4.07
South_Central_Texas	0.67	1.22	30.03	0.16	15388	1.30	6.41	2.21	0.251	0.18	0.18	17.46	36.33	0.03707	1.47	10.29	3.57	5.85
West_Texas	0.24	2.19	503.48	0.17	3915	1.52	2.18	4.55	0.033	0.10	0.20	34.90		0.00514	0.80	6.49	4.80	3.88

Coefficient of Variation - Original Generalized Districts

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay	Mean	Median
East_Texas	13%	8%	84%	6%	179%	6%	10%	1%	39%	14%	59%	90%	105%	66%	35%	28%	17%	23%	44%	26%
Lower_Rio_Grande_Basin	7%	6%	25%	2%	141%	4%	12%	4%		20%				72%	24%	57%	22%	24%	30%	21%
North_Central_Texas	9%	9%	182%	2%	186%	12%	25%	4%	131%	15%	61%	97%	80%	307%	34%	31%	15%	17%	68%	28%
South_Central_Texas	9%	6%	60%	2%	149%	7%	21%	4%	94%	15%	62%	118%	287%	417%	54%	36%	18%	24%	77%	30%
West_Texas	3%	11%	148%	2%	100%	9%	14%	7%	147%	8%	112%	48%		53%	25%	27%	21%	19%	44%	21%

5.3 Revision Methodology and Results

A methodology was devised to test the strength of the grouping as determined by the generalized districts from the NRC Report (2005) and to revise the groupings in a manner that would result in an improved stream classification.

First, the subbasins which lie on the border between two or more groups were identified; there are 50 border subbasins of which 10 border two different neighboring regions (Figure 56 and Appendix B – Supporting Data). A program was written using pivot tables in conjunction with Visual Basic for Applications (VBA) macros in Microsoft Excel to test the value of switching each bordering subbasin into the neighboring district to see if the strength of the classification system improves. Since there are 50 bordering HUCs and 10 have dual neighbors, 60 such trials were conducted. During each trial:

1. one subbasin was switched to its neighboring generalized district,
2. the mean, standard deviation, and coefficient of variation for each of the 18 distinguishing parameters for each district were calculated,
3. the median of these 18 values was calculated for each district,
4. the 5 median values were compared with the 5 median values calculated using the same methodology on the original districts,
5. the change in medians (i.e., level of improvement or lack thereof) were calculated for each district,
6. the changes of all 5 districts were summed, and
7. the switch was determined to be beneficial if it resulted in a decrease in variability within the classes.

Once a trial had determined if a particular switch was beneficial or not, the generalized districts were reset to their original groupings (i.e., a switched subbasin was flagged but returned to its original district), thus enabling the merit of every trial to be tested individually.

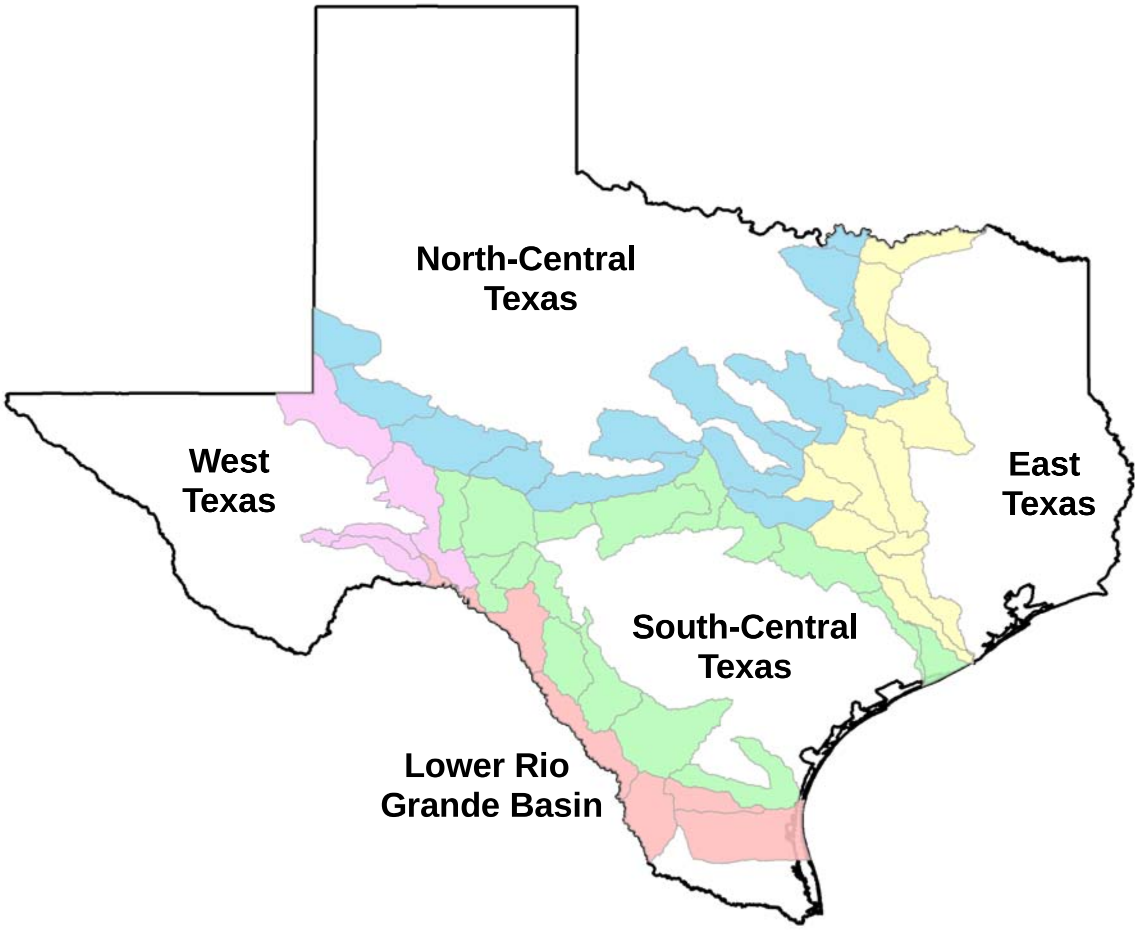

Figure 56. Border subbasins that were tested during the revision process.

From this exercise, it was established that 35 of the 60 trials resulted in improvements to the generalized districts. These 35 successful trials encompassed 31 unique subbasins. In the four HUCs displaying redundancy, the trial which resulted in the greater improvement was retained and the other trial discarded.

The 31 successful trials were next ranked in decreasing order of value; that is, trials that provided the greatest improvement to the system were the most highly ranked. The same testing procedure and program described above was then applied again, this time:

1. one beneficial subbasin was switched to the neighboring generalized district,

2. the same calculations and comparisons were made,
3. the switch was determined to be beneficial or not as above,
4. if beneficial, the switch was made permanent, and the next trial begun;
5. if not determined to be beneficial, the previous switch was discarded and the next trial begun.

In this manner, each successive switch determined to be beneficial resulted in a cumulative improvement in the strength of the classification system. As such, 21 trials resulted in improvements and 10 were discarded, resulting in a 44 percent improvement in the sum of the coefficients of variation for the 5 revised districts. This set of trials can be thought of as the intermediate revised stream classification.

The 21 beneficial switches were viewed in a geographic context and tested according to the following rule: no subbasin may be an island; i.e., a subbasin of one class must border a subbasin of the same class. In addition, subjective judgment was applied to determine if a subbasin shared a sufficient amount of border with neighbors in its own class. This was undertaken as an acknowledgement of the geographic scales of influence of the distinguishing parameters that dictate that close neighbors are more likely than not to share similar characteristics. Trade-off trials were evaluated to see whether the recommend switch provided enough improvement when a neighbor was also switched or if the original trial should be discarded. Ultimately, 25 switches were determined to be beneficial to the classification system, resulting in a 43% improvement in the sum of the coefficients of variation for the 5 revised districts (Table 21, Figure 57, and Figure 58).

Table 21. Subbasins moved between regions during the revision process.

HUC	NAME	ORIGINAL NRC REGION	FINAL REGION
11130210	Lake Texoma	North_Central_Texas	East_Texas
12030103	Elm Fork Trinity	North_Central_Texas	East_Texas
12030105	Upper Trinity	North_Central_Texas	East_Texas
12030108	Richland	North_Central_Texas	East_Texas
12030109	Chambers	North_Central_Texas	East_Texas
12060202	Middle Brazos-Lake Whitney	North_Central_Texas	East_Texas
12060203	Bosque	North_Central_Texas	East_Texas
12060204	North Bosque	North_Central_Texas	East_Texas
12070201	Leon	North_Central_Texas	East_Texas
12070202	Cowhouse	North_Central_Texas	South_Central_Texas
12070203	Lampasas	North_Central_Texas	South_Central_Texas
12070205	San Gabriel	North_Central_Texas	South_Central_Texas
12080003	Monument-Seminole Draws	North_Central_Texas	West_Texas
12080005	Johnson Draw	North_Central_Texas	West_Texas
12090102	South Concho	North_Central_Texas	South_Central_Texas
12090103	Middle Concho	North_Central_Texas	West_Texas
12090106	Middle Colorado	North_Central_Texas	South_Central_Texas
12090109	San Saba	North_Central_Texas	South_Central_Texas
12090110	Brady	North_Central_Texas	South_Central_Texas
12090401	San Bernard	East_Texas	South_Central_Texas
12110104	Turkey	South_Central_Texas	Lower_Rio_Grande_Basin
12110206	Palo Blanco	Lower_Rio_Grande_Basin	South_Central_Texas
12110207	Central Laguna Madre	Lower_Rio_Grande_Basin	South_Central_Texas
13040301	Upper Devils	Lower_Rio_Grande_Basin	West_Texas
13040302	Lower Devils	Lower_Rio_Grande_Basin	South_Central_Texas
13040303	Dry Devils	Lower_Rio_Grande_Basin	South_Central_Texas
13070011	Howard Draw	Lower_Rio_Grande_Basin	West_Texas

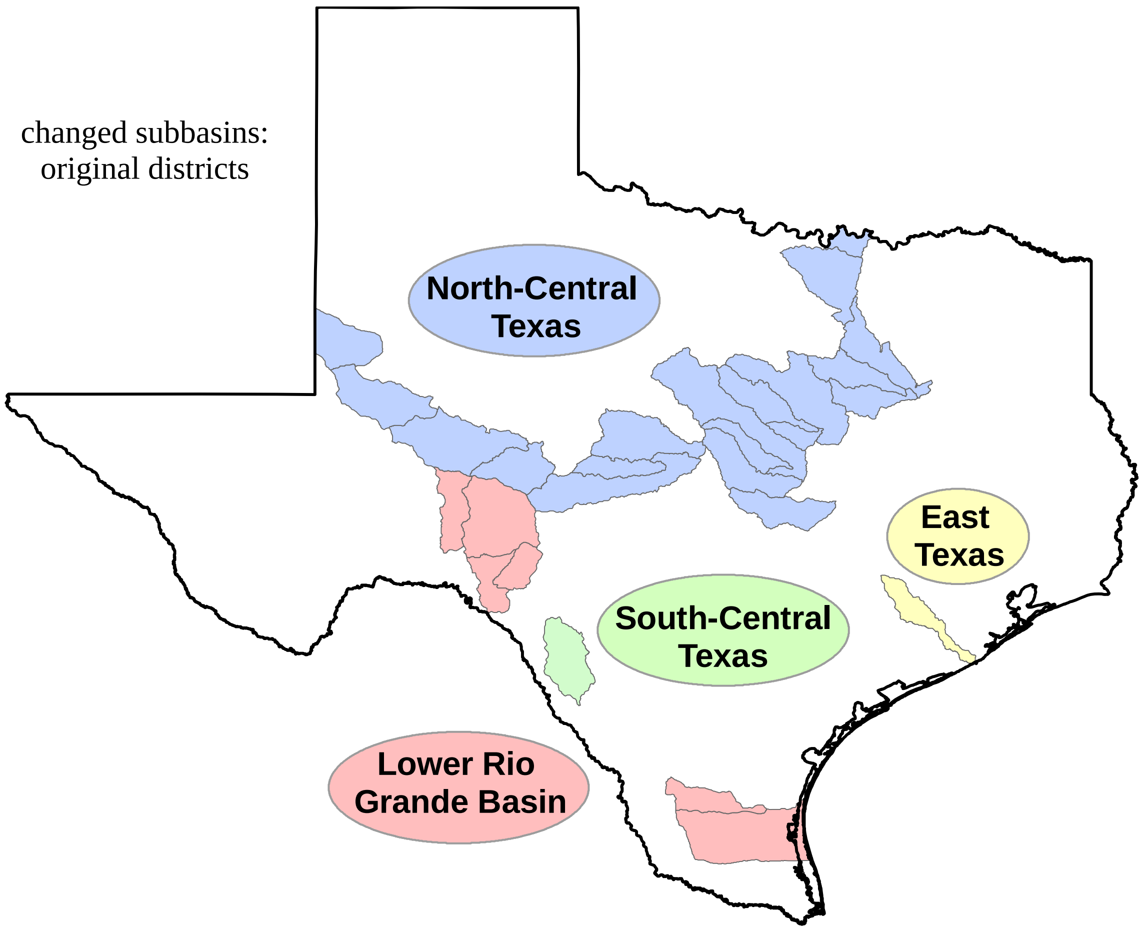

Figure 57. Subbasins moved between regions during the revision process: original NRC districts.

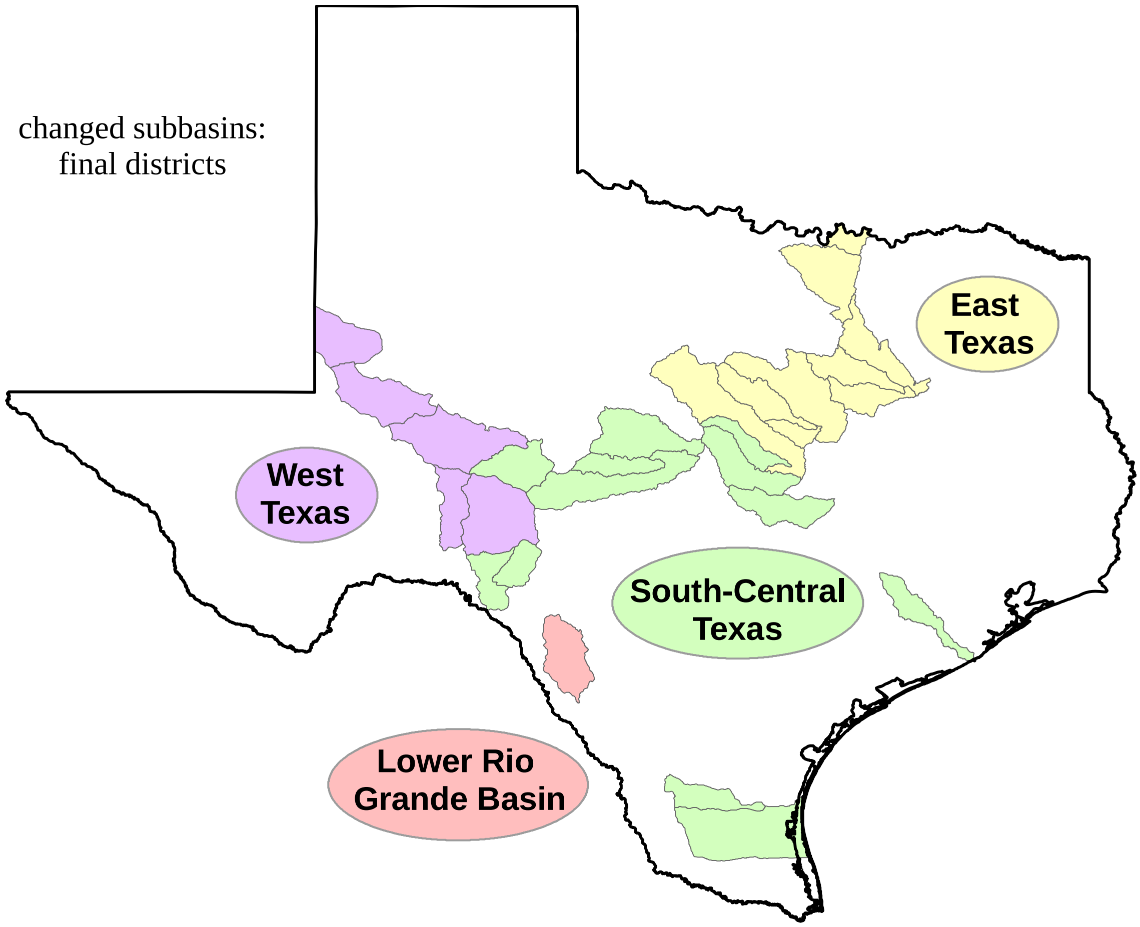

Figure 58. Subbasins moved between regions during the revision process: revised stream classes.

5.4 Revised Classes

Based on the methodology presented herein, results of the testing and revision processes were incorporated into the NRC (2005) generalized districts with consensus-based stakeholder revisions to produce an integrated stream classification system for Texas based on 18 distinguishing parameters encompassing watershed and stream channel processes and functions from four disciplines (Figure 59 and Figure 60). This integrated stream classification system might be used to: (1) discern likely similarities and differences between rivers and streams of the State, (2) remotely characterize stream segments for which resources are insufficient for detailed field studies, (3) recognize streams and watersheds of the State as having common identities, (4) allow conclusions drawn from an instream flow study from a particular river reach to have a wider applicability than the particular study site, and (5) assist in prioritization of rivers and reaches for future instream flow studies. Moreover, the increased range of depth of data resources collected and incorporated into the integrated stream classification system could be of value to stakeholders and regulators.

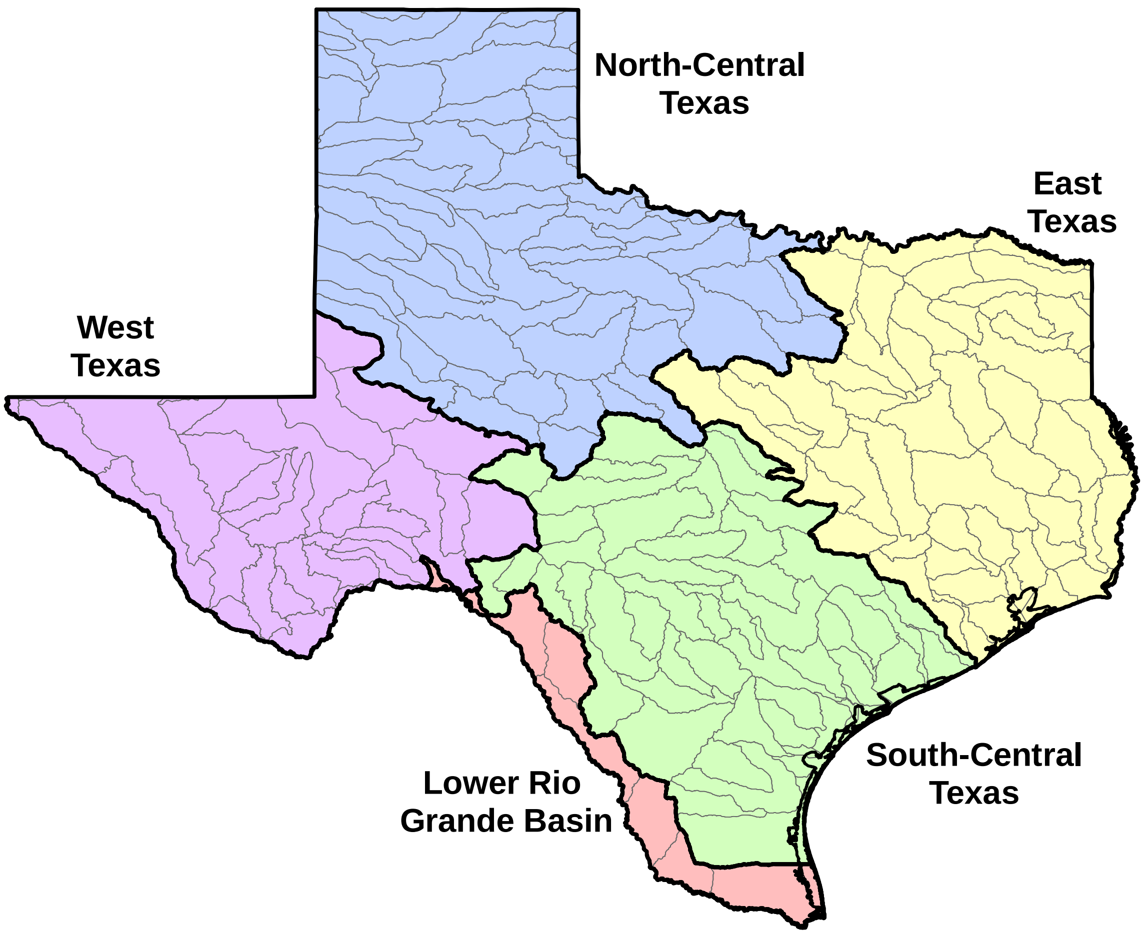

Figure 59. Results of the revision process: the integrated stream classification system for Texas.

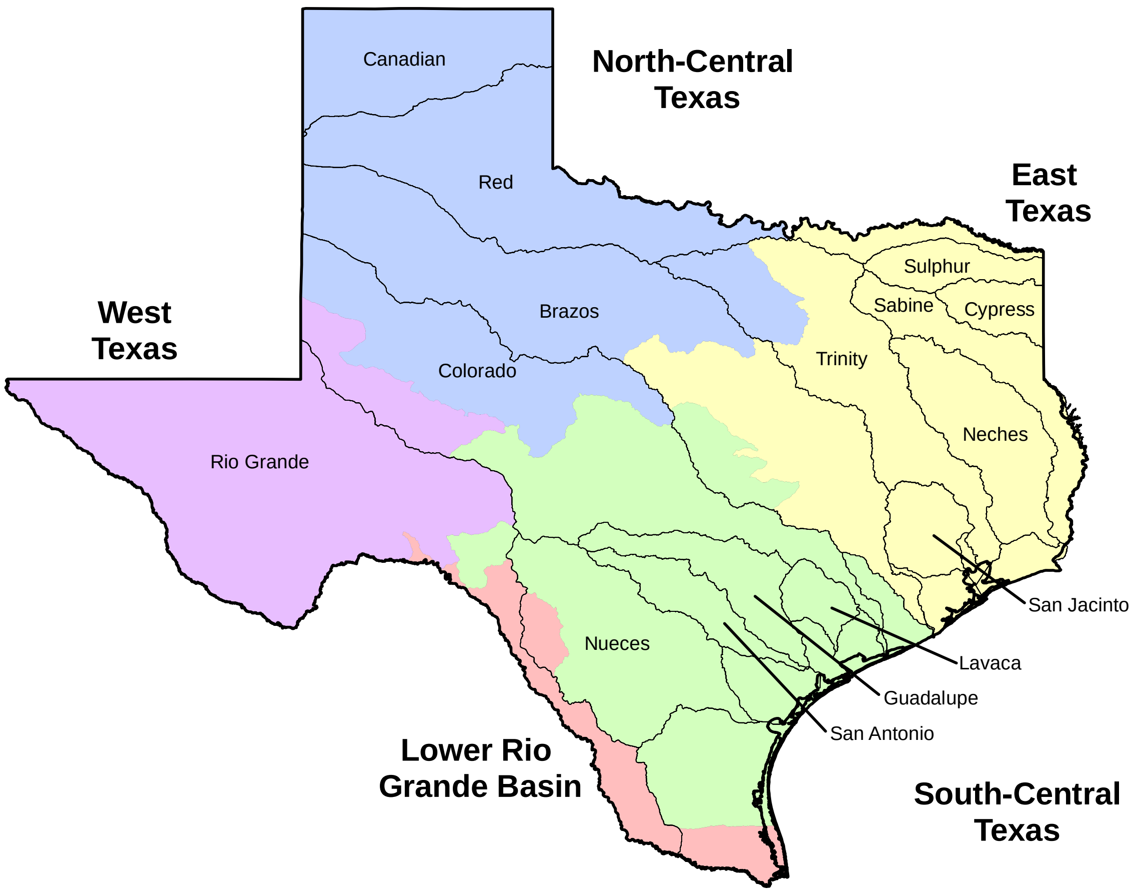

Figure 60. The integrated stream classification system for Texas, overlain with the major river basins of the state.

5.5 Analysis of Revised Integrated Stream Classes

5.5.1 ANALYSIS OF REVISED CLASSES

Similar to that conducted on the original generalized districts, an analysis was made of the eighteen distinguishing parameters based on grouping by the revised stream classification (Table 22 and Table 23). From the data, some generalized patterns are evident.

Table 22. Count and area of subbasins grouped by the revised stream classes.

Class	Count	Total Area (sq km)
North_Central_Texas	67	202,477
East_Texas	50	162,498
South_Central_Texas	55	180,471
Lower_Rio_Grande_Basin	7	24,837
West_Texas	32	122,386
Total	**211**	**692,669**

Table 23. Mean, standard deviation, and coefficient of variation statistics for the revised stream classes of Texas.

Mean - Final Stream Classes

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay
East_Texas	7.49	20.34	39.91	7.44	2471	18.12	44.07	54.91	0.71	1.21	0.26	6.55	6.27	0.0010	2.41	30.07	23.08	24.48
Lower_Rio_Grande_Basin	8.10	22.92	68.38	7.97	8195	21.68	23.23	56.50		0.90	0.28	29.55	4.00	0.0049	2.25	30.52	22.87	23.16
North_Central_Texas	8.64	18.42	165.31	8.05	4863	15.21	22.63	60.00	0.06	1.28	0.18	20.16	4.77	0.0035	2.75	35.66	23.26	24.03
South_Central_Texas	7.90	21.81	49.15	7.95	10129	19.67	31.22	57.92	0.27	1.21	0.30	15.21	11.09	0.0080	2.78	29.16	19.68	24.62
West_Texas	8.31	19.42	300.18	7.98	3240	16.56	15.91	65.92	0.02	1.13	0.24	57.61	16.85	0.0118	3.47	24.97	22.93	20.47

Standard Deviation - Final Stream Classes

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay
East_Texas	0.99	1.34	32.56	0.47	5242	1.03	5.96	0.81	0.33	0.17	0.15	5.40	6.00	0.0007	0.83	9.38	3.63	5.69
Lower_Rio_Grande_Basin	0.46	1.51	12.55	0.01	12927	0.99	2.91	2.48		0.10				0.0032	0.50	19.27	4.81	6.07
North_Central_Texas	0.83	1.68	266.42	0.21	7863	1.79	4.60	1.91	0.06	0.21	0.12	19.71	4.17	0.0084	0.71	8.96	3.69	3.48
South_Central_Texas	0.67	1.41	31.54	0.16	15541	1.35	6.53	2.18	0.25	0.17	0.17	17.00	32.87	0.0342	1.40	11.31	3.22	5.60
West_Texas	0.25	1.92	480.22	0.18	3653	1.42	2.45	4.20	0.03	0.09	0.19	33.47	21.29	0.0189	1.25	9.05	4.52	4.10

Coefficient of Variation - Final Stream Classes

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay	Mean	Median
East_Texas	13%	7%	82%	6%	212%	6%	14%	1%	46%	14%	57%	82%	96%	70%	34%	31%	16%	23%	45%	27%
Lower_Rio_Grande_Basin	6%	7%	18%	0%	158%	5%	13%	4%		11%				65%	22%	63%	21%	26%	30%	15%
North_Central_Texas	10%	9%	161%	3%	162%	12%	20%	3%	110%	16%	67%	98%	87%	240%	26%	25%	16%	14%	60%	23%
South_Central_Texas	8%	6%	64%	2%	153%	7%	21%	4%	93%	14%	59%	112%	296%	428%	50%	39%	16%	23%	78%	31%
West_Texas	3%	10%	160%	2%	113%	9%	15%	6%	104%	8%	78%	58%	126%	160%	36%	36%	20%	20%	54%	28%

With regard to water quality:

- East Texas streams have lower DO and are more acidic, likely evidence of higher organic matter content in the water column and sediment and thus more decay and greater biochemical oxygen demand.
- West Texas and North Central Texas streams have higher DO, possibly linked to their lower mean water temperatures and a lower organic matter content.
- All districts had coefficients of variation for DO of approximately 10 percent.
- Water temperatures are highest in the Lower Rio Grande Basin and South Central Texas where the mean atmospheric (air) temperatures are higher.
- All regions had a water temperature standard deviation of approximately 1 to 2 degrees Celsius and coefficients of variation of approximately 10 percent.
- The mean and standard deviation of TSS is considerably higher in West Texas and North Central Texas and lower in East Texas and South Central Texas.
- With the exception of East Texas, the pH of streams across Texas is very consistent, with an average pH of 8.0 +/- 0.05. East Texas streams had a mean pH of 7.4 +/- 0.5.
- The coefficients of variation for pH for every district were between 0 and 6 percent.
- The mean specific conductance is considerably higher in South Central Texas and the Lower Rio Grande Basin than elsewhere, possibly evidence of increasing stream salinities towards the downstream end of agricultural basins but also of tidally-influenced coastal streams.
- The specific conductance varied widely within a district, with coefficients of variation of 100 to over 200 percent.

With regard to climatology:

- The mean annual air temperature was considerably cooler in the higher elevation regions of North Central Texas and West Texas.
- All mean air temperatures were within 1 to 2 degrees Celsius with coefficients of variation of approximately 10 percent.
- The mean annual precipitation is considerably higher in East Texas and considerably lower in West Texas.
- The precipitation was more variable in South Central Texas and North Central Texas, each of which had coefficients of variation of approximately 20 percent versus 13 to 15 percent for other regions.
- PET was more uniform across the State than precipitation and temperature, as it is a measure of the potential for water to evaporate and transpire irrespective of the availability of water (surficial and as soil moisture) for these processes.
- PET was higher in West Texas than East Texas, but coefficients of variation ranged from 1 to 6 percent.

With regard to hydrology and hydraulics:

- The mean annual normalized streamflow (streamflow contributed per unit of drainage area) was considerably higher in East Texas than anywhere else in the State.
- There was insufficient gaged streamflow data from the USGS in the Lower Rio Grande Basin to derive statistics in that district; these data could be obtained from the International Boundary and Water Commission (IBWC).
- Mean annual streamflow was highly variable in every region of the State with coefficients of variation ranging from 50 to 110 percent.
- Mean annual stream velocity was fairly uniform across all regions, albeit slightly lower in the Lower Rio Grande Basin. Mean velocities were

typically 1.1 +/- 0.2 feet per second with coefficients of variation of around 10 to 15 percent.

- The proportion of streamflow derived from base flow (or BFI) was higher in the wetter areas of East Texas, in South Central Texas where spring-fed streams are more common, and in the Lower Rio Grande Basin, possibly due to irrigation water return flows.
- BFI was variable, with coefficients of variation ranging from 60 to 80 percent.
- The proportion of days experiencing no flow exhibited a strong east-west gradient as expected; more perennial streams are present in wetter East Texas than arid west Texas where intermittent (i.e., ephemeral) streams in are more common.
- West Texas had a considerably higher percentage of zero flow days than any other region as well as a relatively lower coefficient of variation, 60 percent versus 80 to 110 percent for the other regions.
- The variability and flashiness of the streamflow regime was much higher in West Texas and South Central Texas than the remaining regions. The 75th percentile of flow minus the 25th percentile of flow (IQR) in West Texas is almost 17 times the median daily streamflow.
- IQR was highly variable, with coefficients of variation of approximately 90 to 100 percent in East Texas and North Central Texas and nearly 300 percent in the flashier systems of South Central Texas.

With regard to geomorphology and physical processes:

- There was a gradient across the State in average reach slope, with the lower elevation regions of East Texas and South Central Texas having gentler bed slopes than the higher elevation regions of West Texas.
- Bed slope exhibited a range of coefficients of variation, from 60 to 70 percent in the Lower Rio Grande Basin and East Texas to 200 to over 400 percent in North Central Texas and South Central Texas; this is indicative

of the different types of terrain and elevations present within each of these regions. For example, South Central Texas includes portions of the Texas Hill Country but also portions of the very flat coastal plain.

- Mean stream substrate type was generally silt (STORET code 2) to sand (code 3) for all regions except West Texas, which was sand to gravel (code 4).
- Substrate type was fairly uniform, with coefficients of variation in all regions except South Central Texas of approximately 20 to 30 percent; South Central Texas was more variable at 50 percent.
- Watershed soil texture data indicate that there is a greater proportion of sand than silt or clay in every region of the State.
- Proportions of each soil classification were relatively uniform between regions. That is, similar proportions of sand, silt, and clay were present in each region; the sole exception to this result is the reduced proportion of sand in West Texas.
- Although it is evident in the absence from this data and not the presence, this discrepancy is possibly due to elevated gravel content in the watershed soils of West Texas, as the total percentage of soil texture composition for each region does not total 100 percent. Nonetheless, soil texture data within the CONUS-SOILS database was limited to these three soil classes.
- The coefficients of variation of the three soil classes generally ranged from 10 to 30 percent, with the sand content in the Lower Rio Grande Basin and South Central Texas being slightly more variable at 60 and 40 percent, respectively.

When the eighteen multidisciplinary distinguishing parameters are considered in aggregate, the median coefficients of variation for each revised stream class range from 15 percent for the Lower Rio Grande Basin to 31 percent for South Central Texas with an average median coefficient of variation for the stream classes of 25 percent.

Certain variables are much more uniform within a region than others, indicating that their controlling processes operate over a geographic scale which is broader. For example, coefficients of variation for the climatology variables were in the range of 1 to 21 percent with an average (mean) of only 9%, whereas TSS, specific conductance, and stream slope had average coefficients of variation of approximately 100, 160, and 190 percent, respectively. Thus, it is likely that these three parameters are controlled by more localized conditions such as land use, land cover, and local geology or that the variable mean is close to zero. In contrast, DO, water temperature, pH, and stream velocity all exhibited very low variability, meaning that they are likely controlled by more regional forcings.

The process of applying the revision methodology resulted in quantitative improvements in the strength of the stream classification system over the original generalized districts (Table 24). In the climatology variables, the greatest change was observed in East Texas and particularly in precipitation, which had a 40 percent improvement. The greatest changes in geomorphology and physical processes were in West Texas, which experienced improvements in stream slope and substrate of 200 and 140 percent, respectively, and also in East Texas, which had a 50 percent improvement in dominant substrate type.

Table 24. Comparison (percent change) for the mean, standard deviation, and coefficient of variation following revisions.

Mean - Comparison between Original Districts and Final Stream Classes

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay
East_Texas	-9%	1%	6%	-1%	25%	1%	4%	0%	9%	-1%	3%	-9%	-9%	-18%	0%	5%	-1%	-2%
Lower_Rio_Grande_Basin	-6%	1%	-7%	1%	44%	0%	3%	0%		9%	-1%	0%	0%	-20%	9%	17%	-5%	-3%
North_Central_Texas	-9%	2%	-30%	0%	-32%	3%	6%	0%	50%	0%	13%	-7%	8%	23%	3%	-8%	-1%	1%
South_Central_Texas	-5%	1%	1%	0%	2%	0%	-2%	0%	0%	-1%	0%	-3%	13%	10%	-1%	-2%	1%	0%
West_Texas	-1%	-1%	12%	1%	17%	0%	-3%	0%	-8%	-1%	-36%	20%	59%	-21%	4%	-3%	0%	0%

Standard Deviation - Comparison between Original Districts and Final Stream Classes

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay
East_Texas	-18%	14%	9%	-5%	12%	5%	-33%	-18%	-9%	1%	5%	1%	1%	-26%	-49%	-5%	5%	-2%
Lower_Rio_Grande_Basin	44%	-7%	23%	93%	37%	-16%	-3%	-12%		49%				-8%	-2%	8%	-1%	-13%
North_Central_Texas	11%	-1%	-15%	-6%	-14%	5%	25%	27%	58%	-9%	4%	-8%	0%	40%	10%	13%	-5%	14%
South_Central_Texas	6%	-16%	-5%	-3%	-1%	-4%	-2%	2%	1%	7%	6%	3%	10%	8%	-29%	-10%	10%	4%
West_Texas	47%	12%	5%	-5%	7%	7%	-12%	8%	23%	6%	6%	4%		-268%	-128%	-39%	6%	-6%

Coefficient of Variation - Comparison between Original Districts and Final Stream Classes

NRC REGION	DO	Water Temp	TSS	pH	Spec Cond	Atmo Temp	Precip	PET	MAQ	MAV	BFI	Zero Flow	IQR	Slope	Substr	Sand	Silt	Clay	Mean	Median
East_Texas	-9%	13%	3%	-4%	-18%	5%	-39%	-17%	-20%	2%	2%	9%	9%	-7%	-48%	-11%	6%	0%	-7%	-2%
Lower_Rio_Grande_Basin	47%	-7%	27%	93%	-12%	-15%	-6%	-12%		43%				10%	-12%	-11%	4%	-10%	10%	-7%
North_Central_Texas	18%	-4%	12%	-6%	13%	1%	20%	27%	16%	-9%	-11%	-1%	-10%	22%	7%	20%	-4%	14%	7%	9%
South_Central_Texas	10%	-17%	-6%	-3%	-3%	-5%	0%	1%	1%	8%	6%	5%	-3%	-2%	-28%	-7%	9%	4%	-2%	-1%
West_Texas	47%	13%	-8%	-6%	-13%	7%	-9%	7%	29%	6%	31%	-20%		-203%	-136%	-35%	6%	-6%	-17%	-6%

5.5.2 ECOREGION COMPARISON

The integrated stream classes developed here were compared to the Level III Ecoregions of Texas. The ecoregions arose from a federal-level interagency effort to develop a spatial framework of ecological units in the United States “within which biotic, abiotic, terrestrial, and aquatic capacities and potentials are similar.” (McMahon et al. 2001) The ecoregions were further refined in Texas via a cooperative efforts between state and federal agencies (Griffith et al. 2004). The ecoregions are

> “…based on the premise that ecological regions are hierarchical and can be identified through the analysis of the spatial patterns and the composition of biotic and abiotic phenomena… [including:] geology, physiology, vegetation, climate, soils, land use, wildlife, and hydrology.” (Griffith et al. 2004)

Texas is large in both size and ecological diversity, containing 12 level III and 56 level IV (the finest classification level) ecoregions.

When the integrated stream classes are viewed in comparison to the level III ecoregions, differences in the areas subtended become evident (Figure 61). With a few exceptions where an ecoregion is wholly contained within a stream class, the stream classes generally cut across the ecoregion boundaries and vice versa. These differences likely reflect: (1) the conceptual framework under which each classification system was developed; (2) the type and source of data incorporated into each system; and (3) the scales of influence of the incorporated data. As such, a primary difference is rooted in the relative importance and incorporation of primarily-aquatic versus primarily-terrestrial indicators.

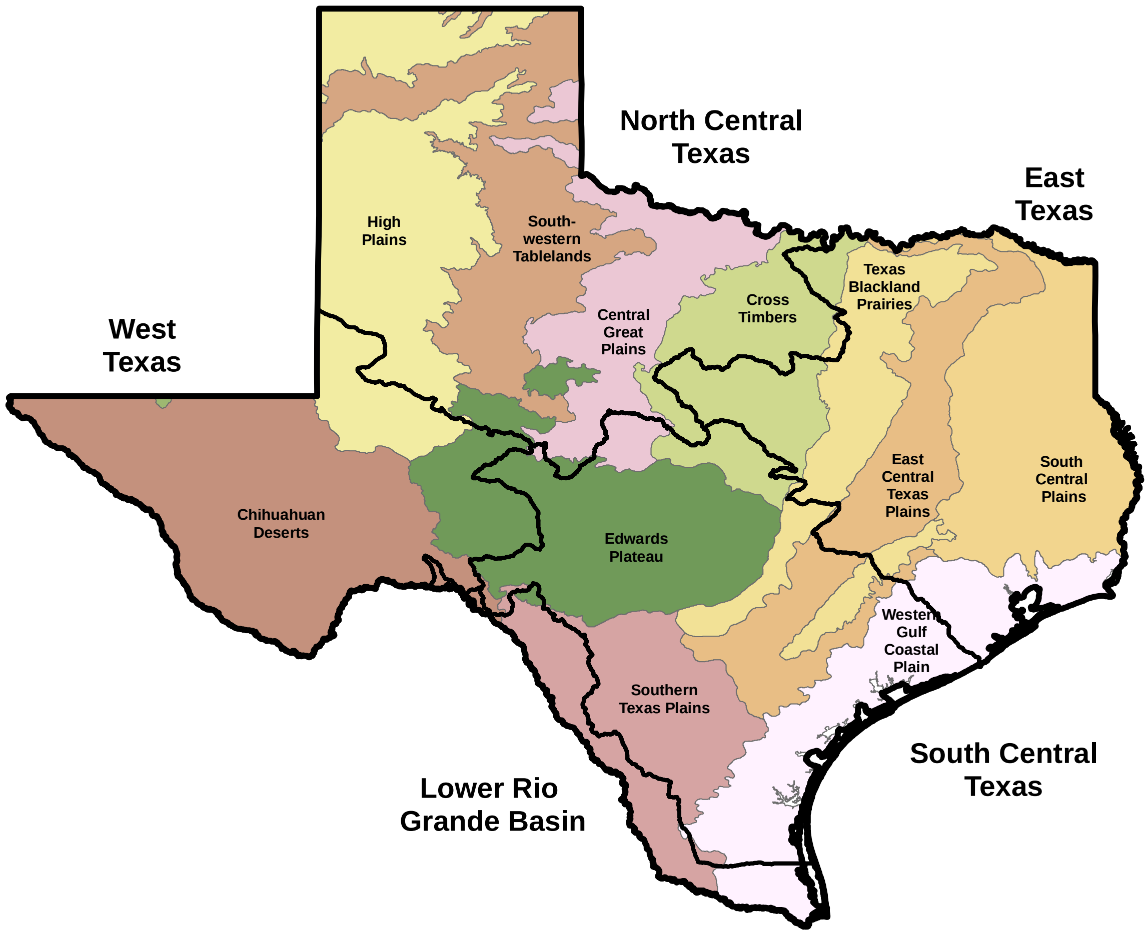

Figure 61. Level III ecoregions of Texas overlain with the integrated stream classes.

5.6 Limitations

The stream classification system presented here incorporates multiple recently developed and published datasets in an integrated fashion to develop a synoptic characterization of streams and watersheds on a broad geographic scale in Texas without any additional field work. As such, it can be used to draw generalizations and answer broad questions about the physical setting for instream flows research and study and for other related riverine analyses. It is not intended to be the final authority on integrated stream classification systems methodology nor of definitive stream classification in Texas, but nonetheless represents a step forward in both of these areas.

The integrated stream classification system for Texas might benefit from future work on:

1. A logical interpretation and integration of geologic data. A project was recently completed to digitize the Bureau of Economic Geology (BEG) Geologic Atlas of Texas (GAT) into both raster and vector formats at a 1:250,000 scale; these data are available from TNRIS. A challenge will be to interpret this data in the context of riverine research and to quantify the impact and relevance of geologic controls and forcings.
2. An evaluation of flowline versus subbasin representation. The distinguishing parameters incorporated exert control on differing spatial scales. As such, some of the parameters might be best represented on a subbasin-scale (by polygon), whereas others may be better represented on a reach-specific scale by flowline (by line). Representing the data in this polygon and line fashion may reveal additional information about particular streams and stream types within a subbasin. For example, small tributaries of the lower Brazos River could be classified differently than the mainstem of the river, a distinction likely to be of importance when characterizing the riverine ecosystem and probable species occurrence.
3. Study of the importance of contributory drainage area to water quality, hydrologic and hydraulic parameters. For example, the percentage of zero flow days and the flow variability are both likely to be affected by the size of drainage area contributing to the streamflow gaging location. One analysis method to determine the effect of drainage area would be to study the parameters in relation to stream order and/or stream size, both of which are value-added attributes within NHDPlus.
4. Further distinction between predominantly naturally-controlled parameters and those which are more affected by anthropogenic influence. One such parameter where a human-influenced signature is likely to emerge is the base flow index at sites located downstream of wastewater return flow outfalls.

5. Investigation into the correlation between salinity and specific conductance and between total suspended solids and turbidity, respectively. The specifics of turbidity measurement and the physics of solids in suspension add sources of error when directly comparing these two indices of stream water quality. For example, the mean TSS in East Texas streams was the lowest of any stream class. Based on collective field experience, it is commonly held that East Texas streams are more opaque and thus more turbid than other streams across the State. It is likely that the prevalence of many very small particles in the water column in East Texas results in a smaller total mass of TSS (as captured on filter paper) than streams with larger particles yet causes very high scattering of light (and thus very high turbidity), whereas fewer larger particles elsewhere would result in higher TSS and lower turbidity.
6. Further research into the evaluation of the level of redundancy of the variables incorporated here and the relative merit of each variable in distinguishing between and among stream classes.
7. Incorporation of biologic data, including information on: species presence/absence, relative abundance, and zoogeography.

6. CONCLUSIONS AND RECOMMENDATIONS

A large number of recently developed and recently publicized data sources have made the present an exciting time for the study of riverine systems, and the near future looks to offer more of the same.

Discussions with project participants and with peers near and far have focused on the need for a methodology to scale up the results of site-specific environmental flow studies (typically habitat-based) into a larger framework for management, regulation, and implementation; integrated stream classification systems are viewed by many to be a promising avenue to accomplish this task. To preserve ecological relevance and thus ensure the protection of a "sound ecological environment," the development of stream classes must take into account the importance of multiple systems and processes typically grouped into the four disciplines of instream flows: (1) Hydrology & Hydraulics (including climatology); (2) Water Quality; (3) Geomorphology & Physical Processes; and (4) Biology.

A qualitative regionalization of Texas streams and rivers is presented in the National Research Council Committee (2005) review of the Texas Instream Flow Program to familiarize readers with the "physical settings for instream flows in Texas." In this project, this qualitative regionalization and its boundaries were examined using quantified criteria. The State of Texas was partitioned into five regions: East Texas, South-Central Texas, Lower Rio Grande Basin, West Texas, and North-Central Texas via a series of qualitative parameters by 8-digit Hydrologic Unit Code (HUC) basin

An analysis was made of the eighteen distinguishing parameters based on grouping by the original NRC Generalized Districts from the "Physical Settings for Instream Flows" description, then a methodology was devised to test the strength of the grouping as determined by the generalized districts from the NRC Report (2005) and to revise the groupings in a manner that would result in an improved stream classification.

The process of applying the revision methodology resulted in quantitative improvements in the strength of the stream classification system over the original generalized districts. The changes in the median of the coefficients of variation for each region ranged from a 20 percent improvement to a 3 percent reduction with a mean change of an 8 percent improvement.

Based on the methodology presented herein, the results of the testing and revision processes were incorporated to produce an integrated stream classification system for Texas based on 18 distinguishing parameters encompassing watershed and stream channel processes and functions from four disciplines. This integrated stream classification system might be used to: (1) discern likely similarities and differences between rivers and streams of the State, (2) remotely characterize stream segments for which resources are insufficient for detailed field studies, (3) recognize streams and watersheds of the State as having common identities, (4) allow conclusions drawn from an instream flow study from a particular river reach to have a wider applicability than the particular study site, and (5) assist in prioritization of rivers and reaches for future instream flow studies. Moreover, the increased range of depth of data resources collected and incorporated into the integrated stream classification system could be of value to stakeholders and regulators.

APPENDIX A – SCOPE OF WORK

The Texas Commission on Environmental Quality (TCEQ) has the statutory obligation to review water rights applications for their potential impacts on aquatic resources and set environmental flow requirements. The agency carries out this charge by relying on a hydrologic desktop method, publicly-available data, and site-specific information collected in the field to make environmental flow determinations. In addition, Senate Bill 2 passed by the 2001 Texas Legislature established for the first time the principle that a "sound ecological environment" in Texas streams and rivers should be protected by the establishment of scientifically-determined instream flow requirements. SB2 provided for a 10-year study period. Studies are currently underway on six priority river segments. In total, however, the segments being studied constitute only 8 of the [189] TCEQ-designated water quality management segments in Texas that are free flowing rivers (i.e., not inland water bodies, tidal reaches or coastal segments). Studies on the remaining [181] segments will take more time and resources than are available, and yet, it is important to characterize the other segments to determine appropriate instream flow requirements.

This project would use GIS technology to organize existing information relevant to the understanding of Texas streams and rivers (i.e., water quality, geologic and geomorphic, hydrologic, and biological data), and develop a classification scheme such that particular classes or regions of streams and rivers could be recognized as having a common identity. Accordingly, conclusions drawn from instream flow studies in particular river reaches might have a wider applicability than the particular study site. The increased range and depth of data resources at the agency's fingertips as it conducts environmental reviews of water rights applications would enhance the quality of those reviews. Moreover, this project could also help prioritize areas for future instream flow studies. A qualitative regionalization of Texas streams and rivers is presented in the National Research Council (2005) report and TCEQ proposes to examine this type of regionalization more closely and attempt to draw its boundaries using quantified criteria that will yield a stream classification system for the state.

Data will be managed in a spatially-explicit fashion, using the geo-referenced databases currently available and under development for the Instream Flows Program, and also building upon current research being performed within the Program. Boundaries drawn will be consistent with the prior delineation of river basins for use in TCEQ's water availability models. Data incorporated into the classification structure may include:

- Hydrology & Hydraulics: USGS discharge and stage data, climate data.
- Biology: Texas Parks and Wildlife Inland Fisheries database, Index of Biologic Integrity metrics.
- Geomorphology & Physical Processes: geology, land use/land cover, soils, channel cross-sectional form and size, channel plan form, bed morphology, and bed slope.
- Water Quality: TCEQ Regulatory Activities and Compliance System (TRACS) database, including: temperature, dissolved oxygen, total suspended solids, and nutrients.

APPENDIX B – SUPPORTING DATA

HUC	NAME	Area sqkm	DO NEW	Water Temp	TSS	pH	Spec Cond	Atmos Temp	Precip	PET	MAQ	MAY	BFI	Zero Flow	IQR	Slope	Subs NEW	Sand	Silt	Clay
11080006	Upper Canadian-Ute	14						13.00	17.00	60.0								42.2	25.0	25.8
11090101	Middle Canadian-Trujillo	3020						13.00	17.00	60.5		1.43				0.0027	3	38.6	22.6	28.3
11090102	Punta De Aqua	1518						12.33	16.00	60.0		1.50				0.0038	3	41.8	19.2	22.7
11090103	Rita Blanca	1905	9.49	14.71	151.1	8.88	703	12.50	16.00	60.0		1.46				0.0035	3	47.3	19.4	20.6
11090104	Carrizo	640						12.50	16.00	60.0		1.53				0.0027	3	51.6	18.8	21.5
11090105	Lake Meredith	5370	9.40	15.29	802.0	8.33	1990	13.20	19.00	59.5	0.014	1.11	0.16	0.84	3.62	0.0047	3	35.1	20.7	24.3
11090106	Middle Canadian-Spring	7281	9.53	16.34	31.5	7.96	3828	13.75	20.60	60.0	0.012	1.02	0.31	0.98	2.20	0.0035	3	35.2	23.1	23.7
11090201	Lower Canadian-Deer	121						13.50	23.00	60.0								48.5	24.2	26.1
11090201	Lower Canadian-Deer	7						14.00	23.00	60.0								44.1	30.9	26.3
11100101	Upper Beaver	623						12.50	17.00	60.0		1.59				0.0037	3	37.4	26.2	22.2
11100103	Coldwater	3747						12.50	17.00	60.0		1.20				0.0029	3	38.6	27.0	23.7
11100104	Palo Duro	4795	8.56	18.33		7.96	344	13.50	18.50	60.0	0.015	1.06	0.05	36.87	4.75	0.0027	2	29.2	24.1	18.7
11100201	Lower Beaver	1112						13.00	21.00	60.0		1.07				0.0016		21.4	23.5	23.6
11100201	Lower Beaver	10						13.00	23.00	60.0								31.1	27.4	24.8
11100202	Upper Wolf	2039	9.65	16.82	22.0	8.08	1104	13.50	21.00	60.0	0.015	1.19	0.46	1.73	1.81	0.0020		40.9	17.8	22.3
11100203	Lower Wolf	1119						13.50	22.00	60.0		1.15				0.0024		43.2	19.1	25.9
11120101	Tierra Blanca	3286	5.01	20.96		7.61	1023	13.50	18.00	60.5	0.005	1.31	0.20	31.73	3.00	0.0017	3	29.4	28.1	29.0
11120102	Palo Duro	2441						13.00	18.00	60.5		1.07				0.0683		28.8	23.9	28.0
11120103	Upper Prairie Dog Town	5505	9.57	16.15	49.8	8.50	2244	13.86	19.00	59.5	0.007	1.52	0.14	5.75	3.34	0.0042	3	37.3	22.4	27.1
11120104	Tule	2859	8.77	13.64	11.0	8.13	522	13.75	19.00	59.5	0.010	1.16	0.03	62.79		0.0036	2	29.5	34.2	32.3
11120105	Lower Prairie Dog Town	3934	8.18	18.43	959.7	7.79	31347	15.50	22.00	59.0	0.015	1.41	0.06	0.14	4.23	0.0019	2	46.5	18.2	22.0
11120201	Upper Salt Fork Red	1927	9.03	16.71	20.1	8.14	699	14.00	22.00	59.0		1.16				0.0036	3	38.8	20.4	24.9
11120202	Lower Salt Fork Red	1422	9.52	17.95	89.5	7.92	2813	15.00	22.00	59.0	0.047	1.35	0.29		1.61	0.0027	2	40.0	21.4	22.1
11120301	Upper North Fork Red	3021	8.36	17.35		8.07	666	13.60	21.50	59.5		1.29				0.0033	3	52.2	20.2	21.0
11120302	Middle North Fork Red	2053	9.22	16.65	94.8	8.02	1468	14.00	22.33	59.0	0.041	1.43	0.38	17.22	6.44	0.0023	3	55.6	22.2	23.4
11120304	Elm Fork Red	833						15.00	23.00	59.0		1.15				0.0038	3	41.4	24.7	25.1
11130101	Groesbeck-Sandy	165						16.00	22.00	59.0		0.84	0.41		1.59	0.0018	3	42.8	18.4	20.1
11130101	Groesbeck-Sandy	1889						16.67	24.00	59.0	0.079	1.22		1.28		0.0012		50.9	17.3	15.4
11130102	Blue-China	152						16.50	27.00	59.0		1.81				0.0011	2	48.1	19.2	19.7
11130102	Blue-China	799						17.00	29.00	58.5		0.97				0.0011		31.0	22.5	23.1
11130103	North Pease	3800	8.76	20.49		7.89	16052	14.50	21.00	59.0		1.35				0.0036	3	37.8	21.9	24.8
11130104	Middle Pease	3696	7.66	20.29				15.00	22.00	59.5		1.25				0.0039	2	42.9	21.3	23.6
11130105	Pease	1988	9.03	19.84	363.8	7.91	12346	16.50	24.00	59.0	0.044	1.45	0.14	11.09	3.63	0.0014	3	40.1	20.3	25.1
11130201	Farmers-Mud	2247	8.74	18.97	7.8	8.06	595	17.25	34.60	57.5		1.01				0.0017	3	27.9	25.3	19.7
11130204	North Wichita	2844	9.55	19.46	46.7	7.89	13080	16.50	24.00	59.5	0.056	1.11	0.39		0.76	0.0018	3	33.8	21.7	22.4
11130205	South Wichita	1835	9.23	19.12	147.3	7.79	23520	16.50	24.00	59.5	0.067	1.11	0.17	11.50	2.05	0.0013	3	29.2	24.9	26.1
11130206	Wichita	2620	9.33	19.47	195.2	7.97	4901	16.50	27.40	58.5	0.067	1.22	0.40	1.30	5.01	0.0007	2	25.6	24.0	24.1
11130207	Southern Beaver	1765	7.62	17.85	111.3	7.81	1699	16.50	27.00	59.0	0.111	1.01	0.09	1.50	2.69	0.0008	1	20.4	17.5	21.8
11130209	Little Wichita	3831	7.62	19.10	57.7	8.19	646	17.67	29.00	58.5	0.115	0.98	0.03	39.42	12.0	0.0008	2	24.7	23.9	27.1
11130210	Lake Texoma	1061	9.60	19.60	12.2	8.01	1783	16.50	39.00	56.5		0.87				0.0004	3	16.7	25.2	25.8
11130301	Washita Headwaters	1160						13.50	22.00	60.0		1.06				0.0028	3	41.7	24.0	25.6
11140101	Bois D'Arc-Island	3682	8.16	18.86	34.7	7.48	351	16.50	42.67	55.5	0.761	1.10	0.12	17.40	4.14	0.0010	1	23.4	26.0	27.4
11140106	Pecan-Waterhole	2076	6.30	17.26	37.1	7.17	350	16.50	47.50	55.5		0.98				0.0011		26.4	27.5	31.0

11140201	McKinney-Posten Bayous	65	5.32	18.81	48.4	6.76	241	17.00	48.00	55.0		0.73				0.0000		29.5	24.5	24.7
11140301	Sulphur Headwaters	2990	8.36	20.29	79.3	7.75	458	17.00	43.67	55.5	0.881	1.15	0.06	10.12	8.24	0.0011	1	22.1	23.9	36.8
11140302	Lower Sulphur	4274	7.76	20.83	47.6	7.56	270	16.50	46.00	55.5	0.898	1.24	0.11	1.22	8.48	0.0008	2	32.8	24.2	24.8
11140303	White Oak Bayou	2038	6.48	19.18	50.2	7.11	366	17.00	44.50	55.0	0.998	1.16	0.08	2.21	6.49	0.0009	1	32.1	21.1	20.4
11140304	Cross Bayou	352	5.69	17.24	21.4	6.56	186	17.00	47.00	55.0		0.96				0.0007		45.7	25.9	23.4
11140304	Cross Bayou	245						17.50	48.33	55.0		1.00				0.0011		33.3	30.4	15.5
11140305	Lake O'the Pines	2342	7.60	21.14	18.2	7.05	237	17.50	45.00	55.0	0.894	1.09	0.24	7.42	3.63	0.0010	3	35.4	25.1	23.2
11140306	Caddo Lake	2801	6.99	19.23	11.8	6.53	121	17.50	47.50	55.0	0.901	1.27	0.41	5.06	3.40	0.0028	1	41.6	28.3	21.4
11140307	Little Cypress	1877	6.46	19.89	18.0	6.63	151	17.50	45.00	55.0	0.772	1.06	0.40	5.87	3.85	0.0005	3	45.5	24.8	16.7
12010001	Upper Sabine	3559	8.20	19.22	32.6	7.76	312	17.00	41.00	55.5	0.737	1.19	0.11	11.20	12.2	0.0008	3	25.5	25.2	28.7
12010002	Middle Sabine	6994	7.42	19.96	26.3	7.05	272	17.50	45.00	55.0	0.736	1.29	0.33	2.66	3.24	0.0006	2	39.2	27.5	20.4
12010003	Lake Fork	1784	8.02	19.05	32.2	7.24	205	17.00	43.00	55.0	0.737	1.13	0.14	6.26	5.11	0.0010	3	37.9	20.3	21.8
12010004	Toledo Bend Reservoir	3680	7.71	19.45	10.1	6.99	177	17.25	51.33	54.5	0.779	1.34	0.39	0.92	3.28	0.0006	3	26.3	26.3	22.9
12010005	Lower Sabine	3674	5.94	21.97	22.9	6.89	4326	18.50	56.00	53.5	0.994	1.53	0.33	5.08	5.67	0.0007	3	33.5	18.5	20.5
12020001	Upper Neches	5022	6.78	18.99	13.6	7.07	175	18.40	42.00	55.0	0.606	1.18	0.45	5.51	3.00	0.0009	3	40.9	25.9	16.8
12020002	Middle Neches	4197	6.98	17.95	34.3	7.20	470	18.67	47.00	54.5	0.538	1.28	0.31	13.95	6.85	0.0007	3	34.8	25.2	18.8
12020003	Lower Neches	2897	6.45	21.80	23.9	7.02	8553	19.00	53.00	53.5	0.725	1.71	0.61	0.05	2.35	0.0008	3	34.7	22.0	21.5
12020004	Upper Angelina	4171	7.69	19.63	13.6	6.99	133	17.50	45.00	55.0	0.712	1.22	0.42	0.97	2.79	0.0006	3	42.9	26.8	19.3
12020005	Lower Angelina	4997	7.44	19.87	17.3	7.05	224	18.00	48.00	54.5	0.910	1.35	0.34	4.63	3.43	0.0007	3	39.9	26.6	17.7
12020006	Village	2845	6.96	20.12	14.1	6.35	97	18.50	52.00	53.5	1.033	1.24	0.40		2.28	0.0006	3	45.5	14.0	8.6
12020007	Pine Island Bayou	1730	5.29	20.55	23.2	6.92	207	19.00	54.00	53.5	1.493	1.24	0.16	0.01	5.30	0.0002	1	36.2	16.3	17.3
12030101	Upper West Fork Trinity	5114	8.85	19.13	24.4	8.05	424	17.80	32.00	57.5	0.190	1.18	0.13	28.79	6.19	0.0011	3	27.8	20.8	24.0
12030102	Lower West Fork Trinity	3924	8.34	19.85	44.6	7.90	494	17.50	34.00	56.0	0.264	1.18	0.18	10.55	5.05	0.0014	3	22.2	23.5	25.2
12030103	Elm Fork Trinity	4790	8.33	19.71	40.2	7.89	434	17.00	38.60	56.5	0.434	1.20	0.20	13.51	5.05	0.0013	3	24.2	26.4	23.5
12030104	Denton	1884	8.65	20.47	26.5	8.00	336	17.75	35.00	57.0	0.263	1.23	0.35	15.70	2.66	0.0014	3	24.1	24.0	22.4
12030105	Upper Trinity	3544	6.80	21.01	111.1	7.58	592	17.60	38.20	55.5	0.723	1.47	0.31	1.86	2.49	0.0012	2	24.3	24.7	33.0
12030106	East Fork Trinity	3409	7.89	20.07	39.8	7.93	367	17.20	40.00	55.5	0.700	1.22	0.22	12.59	32.5	0.0017	3	16.5	25.5	31.2
12030107	Cedar	2767	8.60	20.97	27.7	7.84	200	17.33	40.00	55.5	0.604	1.08	0.03	16.22	7.35	0.0007	2	25.8	22.2	28.3
12030108	Richland	2391	7.99	19.78	17.3	7.88	307	18.50	38.00	54.5	0.481	1.19	0.12	13.02	13.47	0.0008	2	21.4	21.8	37.0
12030109	Chambers	2766	7.92	21.48	56.0	7.92	321	18.00	36.60	55.5	0.506	1.18	0.15	12.03	11.87	0.0010	1	19.3	23.9	29.1
12030201	Lower Trinity-Tehuacana	5505	7.71	19.95	162.2	7.30	347	18.67	41.40	55.0	0.498	1.27	0.32	4.05	3.41	0.0009	3	41.1	19.2	26.3
12030202	Lower Trinity-Kickapoo	8390	8.68	20.94		7.81	394	18.60	45.44	54.5	0.566	1.30	0.32	7.04	24.1	0.0013	3	36.2	20.0	22.5
12030203	Lower Trinity	2103	8.45	22.17	46.0	7.81	683	19.50	51.00	54.0	0.513	1.47	0.64	0.01	1.64	0.0013	2	26.1	21.6	28.0
12040101	West Fork San Jacinto	2792	7.97	21.84	30.6	7.59	257	19.50	47.00	54.5	0.705	1.21	0.18	4.21	10.19	0.0007	3	33.0	21.4	32.4
12040102	Spring	1952	7.50	21.20	55.5	7.45	421	19.50	45.33	54.5	0.615	1.14	0.14	4.02	3.63	0.0008	3	47.0	30.0	24.3
12040103	East Fork San Jacinto	2588	7.98	20.05	24.4	7.06	160	18.50	48.00	54.5	0.804	1.18	0.28	0.78	3.06	0.0010	3	41.1	15.9	13.5
12040104	Buffalo-San Jacinto	2908	6.34	23.37	37.8	7.55	9191	19.50	46.00	54.5	1.521	1.18	0.20	0.64	2.48	0.0007	1	28.5	24.7	22.5
12040201	Sabine Lake	2346	5.82	21.56	26.1	7.38	12209	19.33	52.78	53.0		1.44				0.0001	2	18.5	23.5	22.1
12040202	East Galveston Bay	2036	7.76	21.18	46.3	7.81	18507	19.71	47.83	53.5		1.25				0.0001	2	13.0	17.3	30.2
12040203	North Galveston Bay	1011	8.11	21.36	34.2	8.03	18604	19.50	50.33	54.0	1.313	1.06	0.07	0.39	3.01	0.0002	4	17.2	20.6	24.7
12040204	West Galveston Bay	2871	7.54	21.95	37.4	7.98	21070	20.00	46.28	54.5	1.181	0.96	0.14	1.16	2.52	0.0003	1	15.8	17.2	28.3
12040205	Austin-Oyster	1637	6.30	23.09	41.1	7.77	12250	20.00	49.21	54.5	1.075	1.02	0.60		0.60	0.0001	1	17.2	20.0	30.0
12050001	Yellow House Draw	4139						13.75	18.00	60.0		1.21				0.0070	3	40.4	26.9	21.3

12050002	Blackwater Draw	3542						14.00	18.00	60.0		1.38				0.0015	3	38.2	30.8	25.6
12050003	North Fork Double	2740	8.67	16.43	29.4	8.26	1945	15.00	20.00	60.0		1.74				0.0024	3	37.7	27.0	26.7
12050004	Double Mountain Fork	7109	8.84	17.32	959.0	8.00	4496	15.50	22.60	60.5	0.017	1.52	0.05	32.65	25.0	0.0018	3	36.5	21.9	22.5
12050005	Running Water Draw	3466						13.50	19.00	60.0	0.002	1.24	0.00	85.48		0.0017	3	31.3	34.1	32.9
12050006	White	4393	8.68	16.57	79.7	8.32	867	14.50	19.40	59.5		1.69				0.0032	3	41.6	25.6	26.6
12050007	Salt Fork Brazos	5589	7.98	20.49	700.8	7.91	33610	15.50	21.80	60.0	0.036	1.34	0.13	11.71	3.95	0.0019	3	45.8	22.0	22.7
12060101	Middle Brazos-Millers	6483	8.99	17.96	619.8	8.06	7232	17.00	27.00	59.5	0.051	1.44	0.10	30.46	3.33	0.0013	3	28.9	19.7	27.2
12060102	Upper Clear Fork Brazos	7101	7.93	18.80	52.2	8.12	1787	16.75	25.40	61.0	0.043	1.20	0.22	13.91	8.93	0.0028	1	31.6	26.7	22.6
12060103	Paint	2808	9.24	18.11	87.3	8.20	1826	17.50	25.50	59.5	0.072	1.11	0.11	2.15	2.96	0.0019	3	25.0	20.2	28.4
12060104	Lower Clear Fork Brazos	1607	8.85	19.41	67.8	8.31	2836	17.50	29.00	59.0	0.059	1.49	0.13	11.17	3.40	0.0007	2	24.3	23.7	25.1
12060105	Hubbard	3381	8.37	19.38	14.5	8.00	838	17.50	27.00	59.0	0.106	1.12	0.09	26.16	7.76	0.0024		28.7	23.9	24.9
12060201	Middle Brazos-Palo Pinto	8202	8.40	19.44	70.7	7.98	2786	17.75	30.60	57.5	0.091	1.40	0.12	24.45	4.85	0.0103	3	25.0	19.6	26.2
12060202	Middle Brazos-Lake	6475	8.70	20.52	36.8	7.97	1205	18.40	32.00	56.0	0.190	1.43	0.26	2.76	3.00	0.0042	3	21.9	24.3	27.9
12060203	Bosque	1084	8.62	20.34	20.2	7.95	397	18.00	33.00	55.0	0.347	1.22	0.27	12.11	15.15	0.0024	3	14.1	19.3	26.2
12060204	North Bosque	3208	8.74	19.50	20.7	7.98	651	17.50	32.33	56.0	0.201	1.29	0.18	10.46	4.89	0.0021	3	21.2	22.4	22.1
12070101	Lower Brazos-Little Brazos	7001	8.30	20.94	92.8	7.84	859	19.00	38.00	55.3	0.249	1.41	0.30	14.52	2.23	0.0012	3	31.0	21.5	26.9
12070102	Yegua	3409	6.78	22.25	35.2	7.65	444	19.67	38.00	56.0	0.298	1.11	0.17	14.17	6.33	0.0009	3	33.9	21.1	26.6
12070103	Navasota	5827	7.61	21.31	34.2	7.66	410	18.50	39.33	54.5	0.451	1.21	0.09	10.69	7.17	0.0010	3	31.1	19.6	29.4
12070104	Lower Brazos	4231	7.29	24.56	134.5	7.78	11879	19.50	47.40	55.0	0.484	1.07	0.31	14.04	3.46	0.0027	3	29.3	22.4	26.8
12070201	Leon	7750	8.18	18.59	36.5	7.87	596	18.00	31.33	56.5	0.133	1.26	0.24	11.74	5.92	0.0017	2	28.1	23.0	23.9
12070202	Cowhouse	1928	8.43	21.11	15.8	8.04	400	17.80	31.00	56.5	0.207	1.31	0.20	13.29	6.55	0.0020	3	18.1	18.4	18.0
12070203	Lampasas	3892	8.85	19.37	11.9	7.98	583	18.00	31.00	57.0	0.225	1.25	0.36	10.07	7.52	0.0022	5	18.7	19.9	18.8
12070204	Little	2586	8.70	20.43	162.8	7.94	551	18.50	36.00	55.5	0.216	1.40	0.44	0.02	3.51	0.0008	2	33.7	25.2	28.8
12070205	San Gabriel	3508	8.54	21.66	21.3	7.93	442	18.50	34.00	57.0	0.338	1.22	0.40	2.63	3.87	0.0018	2	19.8	25.9	28.1
12080001	Lost Draw	3460						14.50	18.00	60.5		1.26				0.0017		49.4	26.0	15.5
12080002	Colorado headwaters	6944	8.60	18.58	39.9	8.07	4169	16.50	22.00	62.5	0.020	1.10	0.09	19.13	4.08	0.0020	2	36.1	27.1	21.2
12080003	Monument-Seminole	3736						15.50	16.00	63.0		1.24				0.0020		58.0	20.0	20.2
12080004	Mustang Draw	6285						15.60	17.00	62.5		1.46				0.0012	1	43.2	20.4	18.9
12080005	Johnson Draw	4929						16.33	15.00	64.0		1.09				0.0014		39.8	24.2	20.5
12080006	Sulphur Springs Draw	3921						15.50	18.00	62.5		1.32				0.0045		45.0	26.9	20.6
12080007	Beals	1635	9.17	18.63	99.2	8.11	8642	17.00	20.00	64.0	0.001	1.75	0.11	43.11	2.83	0.0017		33.7	18.0	20.8
12080008	Upper Colorado	3574	9.16	18.86	70.5	8.10	3281	17.00	23.00	65.5	0.005	1.44	0.20	8.85	3.68	0.0025	4	30.1	22.5	21.5
12090101	Middle Colorado-Elm	3007	8.91	19.67	36.9	8.02	2549	17.00	25.50	64.0	0.045	1.47	0.12	15.92	5.42	0.0019	2	29.0	27.7	25.3
12090102	South Concho	3459	8.01	20.23	14.4	8.09	1064	17.00	21.00	67.5	0.040	1.25	0.47	20.46	2.81	0.1109	7	18.6	18.3	13.8
12090103	Middle Concho	6863	8.09	19.59		7.73	638	16.75	18.00	67.0	0.011	1.20	0.21	51.40	6.40	0.0018		19.4	23.3	23.5
12090104	North Concho	3906	7.66	19.46	26.3	7.95	1007	17.25	21.00	67.0	0.017	1.20	0.18	38.75	3.75	0.0019		21.1	20.9	19.1
12090105	Concho	3204	8.82	20.16	29.9	7.96	2092	17.50	23.00	66.5	0.019	1.44	0.23	4.17	2.97	0.0018	5	22.6	23.9	28.3
12090106	Middle Colorado	5111	8.53	18.45	81.6	7.95	1686	17.50	26.00	61.5	0.076	1.44	0.17	43.47	2.87	0.0018	2	23.4	20.3	30.5
12090107	Pecan Bayou	3651	7.45	19.38	27.0	7.89	781	18.00	27.00	59.0	0.080	1.22	0.18	7.23	4.75	0.0023	4	26.3	24.4	27.4
12090108	Jim Ned	2017	8.17	19.99	13.9	7.94	659	17.50	26.33	60.0	0.053	1.16	0.12	51.20	6.67	0.0018	3	21.4	23.5	32.7
12090109	San Saba	6015	7.89	19.76	46.5	8.03	540	17.33	24.00	63.0	0.057	1.30	0.51	1.17	1.20	0.0118	3	25.2	18.4	20.2
12090110	Brady	2020	8.19	19.93	22.5	8.16	1621	18.00	25.00	63.0	0.018	1.30	0.21	33.70	5.15	0.0020	5	21.4	19.6	30.6
12090201	Buchanan-Lyndon B.	3236	8.39	19.38	17.2	7.99	703	18.00	29.00	58.5	0.111	1.60	0.26	3.39	2.47	0.0254	4	24.2	20.6	28.1

12090202	North Llano	2393						17.50	23.67	62.5	0.075	1.23	0.47	5.96	1.36	0.0028	5	19.0	13.1	13.1
12090203	South Llano	2387	8.73	24.59		7.86	416	17.50	25.40	61.0		1.19				0.0044	5	17.4	12.6	14.7
12090204	Llano	6802	8.80	21.03	14.6	8.16	430	17.75	27.00	60.0	0.096	1.47	0.50	0.74	1.22	0.0031	3	29.1	19.1	26.1
12090205	Austin-Travis Lakes	3209	8.16	19.68	65.5	7.87	552	19.00	31.80	57.5	0.478	1.61	0.35	14.61	3.36	0.0086	5	12.6	18.1	32.1
12090206	Pedernales	3310	8.71	21.44	21.1	8.14	608	18.00	30.00	59.0	0.199	1.44	0.39	1.55	1.80	0.0126	7	21.4	22.8	26.2
12090301	Lower Colorado-Cummins	5694	8.33	22.60	31.9	8.19	945	19.50	37.33	57.0	0.155	1.52	0.47	1.23	1.31	0.0020	3	35.5	20.7	21.9
12090302	Lower Colorado	1807	8.18	22.49	121.5	8.01	11082	20.00	41.80	55.5	0.067	1.08	0.49	0.02	1.61	0.0047	1	36.3	21.3	31.5
12090401	San Bernard	2665	7.13	22.17	45.8	7.61	12270	19.50	46.25	55.0	0.761	1.10	0.19		2.52	0.0004	2	24.6	20.3	25.2
12090402	East Matagorda Bay	2181	6.64	21.31	48.1	7.78	14990	20.67	46.14	55.0		0.95				0.0003	1	23.5	17.3	32.5
12100101	Lavaca	2318	8.37	23.12	43.9	8.02	8705	20.50	39.00	56.5	0.468	1.16	0.19	0.59	2.07	0.0007	3	42.4	18.9	24.8
12100102	Navidad	3685	7.77	21.73	50.2	7.70	605	20.50	40.00	56.5	0.684	1.16	0.11	2.08	3.08	0.0006	3	40.2	20.7	27.0
12100201	Upper Guadalupe	3745	8.24	20.65	8.4	8.00	456	17.75	31.67	59.0	0.261	1.24	0.65	0.49	1.03	0.0033	4	15.9	21.7	25.2
12100202	Middle Guadalupe	5519	8.36	21.32	20.6	7.83	616	20.00	33.80	58.0	0.717	1.36	0.50	2.73	2.08	0.0243	2	31.4	20.4	21.5
12100203	San Marcos	3518	8.23	21.56	23.0	7.87	627	18.50	34.50	58.0	0.410	1.29	0.43	8.52	3.76	0.2496	3	17.5	22.1	21.7
12100204	Lower Guadalupe	2710	7.84	23.20	77.8	8.00	672	20.50	35.00	56.5	0.301	1.22	0.35	1.33	1.67	0.0009	3	36.2	19.7	25.3
12100301	Upper San Antonio	1339	7.73	21.43	89.9	7.65	665	19.00	31.00	59.0	0.512	1.23	0.43	4.99	2.06	0.0045	4	24.1	20.3	27.9
12100302	Medina	3526	7.58	20.72	61.5	7.78	591	18.50	31.00	59.5	0.238	1.26	0.48	17.70	1.45	0.0036	4	17.7	27.0	28.7
12100303	Lower San Antonio	3814	6.83	22.06	133.6	7.80	920	20.50	33.00	57.5	0.194	1.28	0.39	8.19	3.44	0.0009	3	40.1	19.1	26.2
12100304	Cibolo	2188	7.55	20.42	46.8	7.81	840	19.00	32.60	58.0	0.226	1.28	0.26	32.10	2.07	0.0016	4	27.8	21.6	28.4
12100401	Central Matagorda Bay	3289	7.47	21.52	59.9	8.05	27466	20.75	41.86	55.5	1.116	0.95	0.12		1.96	0.0026	1	28.5	17.4	34.7
12100402	West Matagorda Bay	2341	7.36	21.08	46.4	8.02	26892	20.75	41.00	56.0	0.776	0.95	0.05	3.88	3.36	0.0005	2	44.2	15.7	21.1
12100403	East San Antonio Bay	998	8.03	21.13	50.8	8.19	23911	21.00	38.67	56.0		1.05				0.0000	3	20.3	17.2	33.8
12100404	West San Antonio Bay	389	8.10	19.40	64.1	8.19	29111	21.00	37.50	56.0							3	24.4	17.4	29.8
12100405	Aransas Bay	2172	7.70	21.64	43.1	8.16	36514	21.00	35.38	56.0	0.514	0.83	0.06	47.82	166.7	0.0003	3	33.5	18.3	27.9
12100406	Mission	2665	7.02	22.57	37.0	7.73	5087	20.50	33.00	56.5	0.186	1.03	0.18	0.02	2.19	0.0010	1	35.8	18.9	24.6
12100407	Aransas	2183	6.32	22.41	59.3	7.73	7049	20.50	33.00	56.5	0.234	1.02	0.11	6.54	3.94	0.0029	1	30.4	19.1	27.9
12110101	Nueces Headwaters	2114	8.87	21.90	10.2	7.88	419	18.50	25.00	60.5	0.223	1.31	0.64		1.22	0.0040	5	13.4	27.1	18.5
12110102	West Nueces	2340						19.00	25.00	60.5	0.050	1.32	0.12	43.87	15.56	0.0026		13.9	17.8	14.9
12110103	Upper Nueces	4827	8.19	22.51	18.8	7.87	564	19.50	24.00	59.5	0.061	1.19	0.32	24.80	139.7	0.0012	2	35.4	18.6	16.8
12110104	Turkey	4088						20.00	22.00	59.5		1.06				0.0017	2	37.8	18.0	20.3
12110105	Middle Nueces	8607	7.56	22.96	67.6	7.91	1160	21.67	24.00	58.0	0.070	1.17	0.10	38.63	52.7	0.0012	2	35.0	18.6	19.8
12110106	Upper Frio	6100	8.36	21.23	16.5	7.83	854	19.00	25.67	59.5	0.202	1.21	0.40	23.53	2.72	0.0025	2	30.3	25.7	17.6
12110107	Hondo	2827	9.19	22.40	15.3	7.96	460	19.00	28.00	59.5	0.272	1.19	0.25	45.77	2.52	0.0024	1	25.1	27.6	19.0
12110108	Lower Frio	3161	7.65	22.33	53.1	7.95	946	20.50	26.00	58.0	0.049	1.29	0.20	7.87	3.72	0.0010	1	31.4	21.2	21.8
12110109	San Miguel	2214	6.95	22.62	65.0	7.76	1750	20.50	27.00	58.5	0.074	1.17	0.05	25.99	4.89	0.0011	1	41.9	21.4	20.0
12110110	Atascosa	3631	6.98	22.75	52.0	7.82	1661	20.50	27.00	58.0	0.108	1.08	0.11	4.12	1.89	0.0011	1	47.5	20.6	24.8
12110111	Lower Nueces	3472	8.26	23.20	100.4	8.08	18681	21.50	29.00	56.5	0.048	1.31	0.27	1.27	2.70	0.0007	1	40.2	16.0	24.7
12110201	North Corpus Christi Bay	434	7.45	22.47	57.1	8.09	42581	21.50	32.00	56.0		1.50				0.0000	3	16.8	15.5	36.4
12110202	South Corpus Christi Bay	1133	7.28	23.09	66.4	8.06	42310	21.20	33.14	56.0	0.334	0.87	0.11		1.09	0.0005	3	44.9	20.0	28.8
12110203	North Laguna Madre	581	7.19	23.45	28.9	8.24	53112	21.33	30.33	56.0		0.97				0.0005		33.0	17.4	32.3
12110204	San Fernando	3416	8.27	24.15	76.3	8.04	3633	21.50	27.00	56.5	0.035	1.08	0.14	31.93	0.63	0.0016	1	35.5	21.5	26.0
12110205	Baffin Bay	5416	7.60	23.84	72.5	8.07	44578	21.67	26.78	56.0	0.014	0.98	0.07	62.44		0.0012	2	39.8	14.7	20.3
12110206	Palo Blanco	2551						21.50	25.00	56.0		1.11				0.0017	3	55.9	16.5	20.9

12110207	Central Laguna Madre	9153	6.99	23.75	38.0	8.21	52945	21.71	26.83	55.0		1.35				0.0024	3	62.7	19.1	20.1
12110208	South Laguna Madre	7418	7.22	24.54	73.5	7.97	33193	22.50	26.63	54.5		0.74				0.0005	2	35.2	22.4	26.9
13030102	El Paso-Las Cruces	268	8.41	16.66	245.7	8.13	1435	16.00	11.00	78.0		0.77				0.0016	3	41.4	16.1	14.7
13040100	Rio Grande-Fort Quitman	4580	8.66	16.80	183.9	8.17	1614	15.13	11.75	75.5	0.004	1.02	0.00	99.90		0.0119		23.6	20.5	23.1
13040201	Cibolo-Red Light	5559	7.96	19.31	475.0	7.79	2145	16.50	13.55	69.5		1.09				0.0121	3	21.3	20.3	17.9
13040202	Alamito	4011						16.14	16.80	65.0		1.25				0.0091	3	18.0	23.9	22.8
13040203	Black Hills-Fresno	1588						18.57	13.00	64.5		1.11				0.0196	3	23.0	24.5	28.3
13040204	Terlingua	3303						17.36	16.64	64.0		1.15				0.0084	3	19.8	25.2	25.6
13040205	Big Bend	2820	8.31	21.48	1419	8.00	1852	19.29	14.00	63.5		1.07				0.0151	3	25.2	23.6	26.4
13040206	Maravillas	3379						16.73	16.85	63.5		1.26				0.0097	4	22.5	17.2	20.4
13040207	Santiago Draw	1763						17.33	15.75	63.5		1.20				0.0131	2	24.7	20.9	22.3
13040208	Reagan-Sanderson	1406						17.50	15.00	62.0		1.16				0.0084	4	21.6	28.9	20.3
13040208	Reagan-Sanderson	450						18.25	13.00	63.0		1.09				0.0258		30.5	18.2	28.1
13040209	San Francisco	2603						17.17	15.00	63.5		1.21				0.0089	4	20.9	15.9	15.8
13040210	Lozier Canyon	2359						17.50	16.20	62.5		1.18				0.0067	5	22.1	29.5	19.9
13040211	Big Canyon	2106						16.43	18.00	63.0		1.20				0.0054		25.0	33.1	24.1
13040212	Amistad Reservoir	5105	8.51	20.60	88.4	7.98	1006	19.75	20.00	61.0		0.98	0.28	29.55	4.00	0.0052		18.5	19.4	19.6
13040301	Upper Devils	6773						18.00	21.00	64.0		1.10				0.0035		16.7	27.1	28.7
13040302	Lower Devils	2293	9.03	20.67	5.1	8.02	809	19.00	21.00	61.5	0.069	1.27	0.66		0.49	0.0041		14.8	23.5	30.5
13040303	Dry Devils	1866						19.00	22.50	61.5		1.17				0.0041		9.7	15.2	14.9
13050003	Tularosa Valley	394						16.00	12.00	77.5								24.0	19.7	22.3
13050004	Salt Basin	14542						14.29	15.45	72.0		1.09				0.0071	2	20.2	21.0	19.7
13060011	Upper Pecos-Black	196						13.25	19.00	68.5		1.14				0.0158		22.0	28.3	18.6
13070001	Lower Pecos-Red Bluff	10919	8.31	18.48	28.0		9945	16.73	14.00	66.0	0.002	1.07	0.39	32.91	41.35	0.0052		30.1	18.6	15.4
13070002	Delaware	1930						13.91	18.00	68.0		1.09				0.0099		20.5	23.8	16.4
13070003	Toyah	2649						15.00	17.22	65.0		1.13				0.0118		22.4	21.5	21.3
13070004	Salt Draw	5244						14.85	15.00	66.0		1.11				0.0095	3	21.0	18.9	20.1
13070005	Barrilla Draw	2198						15.00	17.00	65.0	0.060	1.22	0.14	83.37		0.0079		19.8	21.1	21.4
13070006	Coyanosa-Hackberry	3826						15.38	17.91	64.5		1.17				0.0075	3	24.6	20.0	22.1
13070007	Landreth-Monument	6925						17.33	13.00	63.5		1.07				0.0030		47.1	19.7	15.1
13070008	Lower Pecos	7626	8.64	19.76	23.7		9317	18.67	18.00	62.5		1.05				0.0066		20.4	27.6	17.5
13070009	Tunas	2591						17.00	17.00	63.5		1.17				0.0073		23.1	32.3	17.8
13070010	Independence	1979	8.38	22.44	11.6		1154	18.00	16.00	63.5		1.12				0.0055		19.5	28.2	16.1
13070011	Howard Draw	2870						17.50	18.00	63.5		1.12				0.0036		17.3	25.2	15.5
13080002	San Ambrosia-Santa Isabel	4511	8.12	21.95	60.0		1112	21.50	21.00	58.5		0.93				0.0053	2	30.1	20.2	17.3
13080003	International Falcon	4645	8.10	22.76	61.2		1068	21.50	21.00	57.0		0.87				0.0094	3	29.6	18.1	26.4
13090001	Los Olmos	2939	8.41	23.21	53.8		11468	21.50	22.00	55.0		0.96				0.0042	2	20.9	20.7	16.3
13090002	Lower Rio Grande	144	8.24	24.46	73.4		1320	22.50	25.00	54.5								9.7	29.3	22.2
13090002	Lower Rio Grande	75						22.50	27.00	55.0								69.7	29.9	33.3
	Count		**156**	**156**	**148**	**148**	**155**	**211**	**211**	**211**	**129**	**203**	**130**	**121**	**125**	**203**	**167**	**211**	**211**	**211**
	Null		**55**	**55**	**63**	**63**	**56**	**0**	**0**	**0**	**82**	**8**	**81**	**90**	**86**	**8**	**44**	**0**	**0**	**0**

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